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DEEP SPACE THERMAL CYCLE TESTING OF ADVANCED X-RAY ASTROPHYSICS FACILITY - IMAGING (AXAF-I) SOLAR ARRAY PANELS TEST

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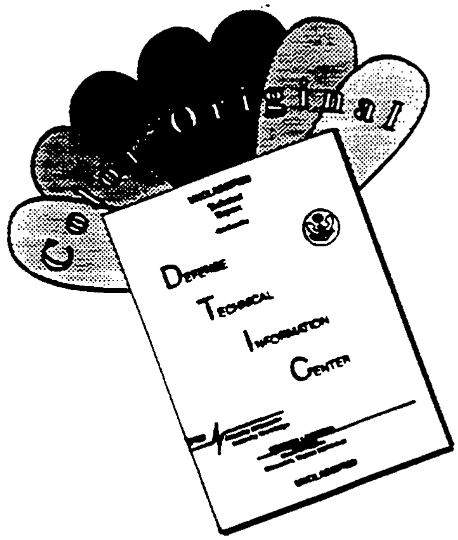

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13. ABSTRACT (Maximum 200 words)

The NASA Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) satellite will be exposed to thermal conditions beyond normal experience flight temperatures due to the satellite's high elliptical orbital flight (Fig. 1). The solar panels, solar cells, wiring, adhesives, and connectors have never been tested at temperatures below -175 C (98.15 K). Two developmental solar array panels (DVT), 16-in. square by 1-in. thick each, were thermally cycled in Arnold Engineering Development Center (AEDC) 7A Thermal Vacuum Chamber. Upon material validation, a Proto-flight solar array panel, approximately 7-ft square by 2-in. thick, was assembled and thermally cycled in AEDC's 10V Thermal Vacuum Chamber.

The primary objective of test phase 1 was to thermally cycle two solar array sub-panels. Performance parameters validated included temperature cycling fatigue, model validation, solar cell sandwich stack separation, solar cell continuity, solar cell adhesive evaluation, on-board wiring evaluation, connector capability, and laminated panel survivability. The solar panels underwent three separate pumpdowns comprised of thermal cycles, 1-8, 9-89, 90-153, totaling 153 thermal cycles. Thermal cycles 1-8 ranged the panel's temperature from 72°C to -201 C and thermal cycles 9-153 ranged the panel's temperature from 62 C to -191 C. AEDC's 7A Thermal Vacuum Chamber provided the necessary environment to perform theses evaluations.

The primary objective of test phase 2 was to thermally cycle a Proto-flight solar array panel. Performance parameters to be validated included the DVT's lessons learned and workmanship factor from the small DVT's to the full-scale solar panel array. The solar panel underwent 11-1/2 thermal cycles ranging from 72 C to -196 C. AEDC's 10V Thermal Vacuum Chamber provided the necessary environment to perform these evaluations.

14. SUBJECT TERMS

AEDC, Thermal Vacuum, bakeout, NASA-MSFC, Ghe, Deep Space, 10 K background, 7A Chamber, 10V Chamber, IR heat lamp arrays, AXAF-I, solar arrays

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PREFACE

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Materiel Command (AFMC) under Program Element 921Y01 and Element 921E02 at the request of the NASA-Marshall Space Flight Center, Huntsville, AL. NASA-MSFC Program Manager of this project was Dr. Frank Fogle of NASA-Marshall Space Flight Center, Huntsville, AL. Capt Jeremy Holtgrave and Lt Nick McKinzey were the AEDC Air Force Project Managers for Phase 1 (DVT Solar Panels). Robert W. Smith was the AEDC Air Force Project Manager for Phase 2 (Proto-flight Solar Panel). AEDC Project Engineer was Jimmy D. Sisco of Sverdrup Technology Inc. Test results were obtained by Sverdrup Technology, Inc., AEDC Group, testing contractor for the AEDC, AFMC, Arnold Air Force Base, TN and NASA-MSFC, Electrical Division, Power Branch, Energy Conversion and Storage Team, NASA-MSFC, Huntsville, AL. The DVT Solar panels test was performed in 7A Thermal Vacuum Test Facility from February 10, 1995 through July 12, 1995, under AEDC Project Number 2538 Phase 1. The Proto-flight Solar panel test was performed in 10V Sensor Test Facility from October 10, 1996 through November 22, 1996, under AEDC Project Number 2538 Phase 2.

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1.0 INTRODUCTION

The NASA Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) satellite will be exposed to thermal conditions beyond normal experienced flight temperatures due to the satellite's highly elliptical orbital flight (Fig. 1). The solar panels, solar cells, wiring, adhesives, and connectors have never been tested at temperatures below -175°C (98.15 K). Two developmental solar array panels (DVT), 16-in. square by 1-in. thick each, were thermally cycled in Arnold Engineering Development Center (AEDC) 7A Thermal Vacuum Chamber. Upon material validation, a Proto-flight solar array panel, approximately 7-ft square by 2-in. thick, was assembled and thermally cycled in AEDC's 10V Thermal Vacuum Chamber.

The primary objective of test phase 1 was to thermally cycle two solar array sub-panels. Performance parameters validated included temperature cycling fatigue, thermal model validation, solar cell sandwich stack separation, solar cell continuity, solar cell adhesive evaluation, on-board wiring evaluation, connector capability, and laminated panel survivability. The solar panels underwent three separate pumpdowns comprised of thermal cycles, 1-8, 9-89, 90-153, totaling 153 thermal cycles. Thermal cycles 1-8 ranged the panel's temperature from 72°C to -201°C and thermal cycles 9-153 ranged the panel's temperature from 62°C to -191°C. AEDC's 7A Thermal Vacuum Chamber provided the necessary environment to perform these evaluations.

The primary objective of test phase 2 was to thermally cycle a Proto-flight solar array panel. Performance parameters to be validated included the DVT's lessons learned and workmanship factor from the small DVT's to the full-scale solar panel array. The solar panel underwent 11-1/2 thermal cycles ranging from 72°C to -196°C. AEDC's 10V Thermal Vacuum Chamber provided the necessary environment to perform these evaluations.

This report does not include all the data obtained during the tests but describes the particulars of each test phase and presents typical results from each phase. The equipment used to accomplish the test objectives is also discussed. Data required to evaluate the performance of these panels relative to the specifications were obtained by NASA-MSFC/TRW team at AEDC and transmitted via internet to NASA-MSFC at Huntsville, AL and TRW at Redondo Beach, CA.

2.0 APPARATUS

2.1 7A THERMAL VACUUM CHAMBER (PHASE 1)

The 7A Thermal Vacuum Chamber (Fig. 2), located in the Space Systems Research Laboratory at Arnold Air Force Base, TN, was designed for general purpose testing of space components. The 7A Chamber is nominally a 3-ft diam by 6-ft long horizontal test chamber. Its vacuum shell is constructed of 6061 T6 Aluminum and is equipped with a GHe cooled liner, operational at an average of 10K to simulate the thermal environment of space. The working volume within the chamber is nominally 30-in.-diam by 5 ft in length. Access to the 7A Chamber is through a 3-ft-diam bulkhead opening on the north end of the chamber. The AXAF-I DVT solar panel arrays were tested under vacuum and at various thermal cycle temperatures.

2.1.1 7A PUMPING SYSTEM

The primary vacuum pumping system is provided by a 360 l/s turbomolecular pump backed by a mechanical roughing pump. A LN2 cold-trap is used for additional pumping and to prevent test volume contamination. The GHe cryo-liner (10K) provides additional cryo-pumping to the chamber. The pumping system has an individual isolation valve with a safety interlock system that automatically isolates the vacuum pumping systems from the chamber in case of power, air, or cooling water failure and/or if the turbopump foreline pressure exceeds normal operational limits.

2.1.2 7A IR HEAT LAMP ARRAY

An IR heat lamp array and frame was mounted inside the cryo-liner with the lamps located on the bottom side of the chamber. The IR heat lamp array consisted of 12 tungsten lamps arranged in a 30-in. by 5-ft array with spacing as required for maximum uniformity (Fig. 3). The lamps were mounted on aluminum channel with "D-tubing" welded to the back side to allow active GHe cooling of the lamp frame. The lamp reflectors were heat sunk to the lamp frame using 3-in. by 3-in. copper shims, and the lamp assemblies were mounted using stainless-steel channel nuts to allow fine tuning of the lamp spacing. The lamp wiring was Teflon® insulated 10-gage wire with Teflon tape used at the lamp terminals. Type T thermocouples were attached to the lamp frame and lamp reflectors. A side tray frame, mounted to the lamp array, provided ease of installation and removal the test article. The frame located the DVT solar array panels 11 in. above the lamp array. The entire lamp array assembly was insulated using multiple layers of aluminized Mylar® (Fig. 4).

The tungsten lamps were rated for 120 volts at 500 W each. The wiring for the lamp array was broken down into three groups of four lamps each for a total of 12 lamps. The power for each group was controlled by a 0-120 Vac supply (Fig. 5). Total full load amperage of each group was 16.7 amp for a total of 6 kW for the entire array.

2.2 10V THERMAL VACUUM CHAMBER (PHASE 2)

The 10V Thermal Vacuum Chamber is located in a large Class 10,000 clean room environment (Fig. 6). The chamber (Fig. 7) is nominally a 10-ft diam by 30-ft length horizontal test chamber. The vacuum shell is constructed of 304 stainless steel, and it is equipped with slide rails to allow a system or optical bench to be rolled into the chamber. Access to the 10V Chamber is through two 10-ft-diam bulkheads located on the east and west ends of the chamber. A 2.5-ft wide by 4.5-ft high entry is located in the middle south side of the chamber. The 20-ft-long by 9.5-ft-diam cryo-liner is located in the west end of the chamber. The Proto-flight solar panel array was installed and removed through the east 10-ft-diam bulkhead.

2.2.1 10V PUMPING SYSTEM

The chamber was evacuated in stages with a combination of vacuum pumping components which include two mechanical roughing pumps with blowers, two 400 l/s turbomolecular pumps, and two 3000 l/s cryo-pumps. The pumping system is mounted outside the clean room on the bottom of the chamber. The cryo-liner also contributes to the pumping capacity of the chamber. Safety system interlocks automatically isolated the vacuum pump systems from the chamber in case of power, air, or cooling water failure or if the turbopump foreline pressure exceeded normal operating limits.

2.2.2 10V IR HEAT LAMP ARRAY

The 10V IR heat lamp array consisted of 54 tungsten lamps arranged in an 8-ft by 8-ft array with spacing as required for maximum uniformity (Figs. 8 and 9). The lamps were mounted on aluminum channel with "D-tubing" welded to the back side to allow active GHe cooling of the lamp frame. The lamp reflectors were heat sunk to the lamp frame using 3-in. by 3-in. copper shims, and the lamp assemblies were mounted using stainless-steel channel nuts to allow fine tuning of the lamp spacing. The lamp wiring was Teflon insulated 10-gage wire with Teflon tape used at the lamp terminals. Type T thermocouples were attached to the lamp frame and lamp reflectors. The entire

array was insulated using multiple layers of aluminized Mylar® (Fig. 10) and assembled into a modular design for moving in and out of the 10V chamber.

The tungsten lamps are rated for 120 volts at 500 W each. The power supply of the array utilized a three-phase, 120V/208Y supply dividing the array into three groups of 18 lamps each for a total of 54 lamps. Each phase was again divided into three circuits inside the chamber to minimize wire size. Total full load amperage of each phase was 75.6 amp for a total of 27 kW for the entire array.

Power to the lamps was provided by a 45 KVA, 480V - 120V/208Y transformer through a 100-amp, 3-pole fused disconnect switch. This power was controlled through three 90-amp, 240Vac solid-state relays with dc pulse control provided from a PID temperature controller. The solid-state relays were protected by fast blow rectifier type fuses. The feedback to the control system was from a user-supplied type T thermocouple output monitoring the average temperature of the test article. A user-supplied relay contact controlled the cycle times by applying power to the PID controller as required by the test matrix. Other features of the control system included an emergency shut down on sensing of over temperature utilizing an independent controller and a three-phase, 100-amp mercury relay. Current monitoring was provided utilizing three 30:1 current transformers connected to three 0-150 amp analog ammeters as shown in Fig. 11. The lamp controller is shown in Fig. 12.

The lamp array and associated power and controls were all tested successfully at ambient conditions prior to the installation of the solar panel. However, at cold test conditions, the impedance of the tungsten filaments decreased appreciably thus increasing the in-rush current to values that caused the rectifier fuses to open when power was applied. This required the addition of a "pre-warm" circuit to raise the lamp impedance to a value that would allow application of full load voltage. The pre-warm was accomplished using a low voltage/high current AC supply which was switched on for 5 min at the beginning of each new heat cycle, thus solving the in-rush problem.

2.3 3 kW GHe REFRIGERATION SYSTEM

The 7A and 10V chamber GHe liners are attached to the closed loop high-pressure GHe distribution system. The 7A Chamber is normally cooled with the 400-W helium refrigerator co-located in the lab; however, since the heat load was estimated at 6 kW, the 3 kW GHe refrigerator was employed. The 10V chamber is normally cooled with the 3 kW. The heat load for the 10V Chamber was estimated at 27 kW.

The term 3 kW denotes the refrigeration system can maintain GHe at 20 K with a 3 kW heat load. The 3 kW refrigeration system consists of an expander, three engines,

and multiple compressors. The 3 kW operates with as few as 1 - 200 W compressor; however, the amount of compressors used are dictated by the required rate of cooling and ultimately the gas line sizes. The refrigerator bypasses excess gas to prevent overdriving the system. A maximum of 3 - 600 W compressors were used on both 7A and 10V test chambers. The 7A and 10V Chamber gas lines restricted the amount of gas flow, resulting in bypassed gas after the third compressor was turned on.

2.4 TEST ARTICLES

There were four test articles: a representative scrap, two DVT solar array panels, and the Proto-flight solar array panel. The representative scrap panel was a piece of laminated graphite honeycomb board with solar cells mounted on it (Fig. 13). The scrap panel was used as an initial temperature indicator for the checkout pumpdown. The DVT solar array panels, 16-in. square by 1-in. thick, were a sample of the materials and manufacturing process of the flight hardware for AXAF-I flight hardware solar panels. The panels weighed approximately 1 lb each with solar cells mounted on one side (Fig. 14) and wire routing on the other side (Fig. 15). The DVT's sample hardware included solar cells, glass cover plates, optical coatings, epoxies, solar cell sandwich stacks, solar cell string circuitry, adhesives, on-board wiring, connectors, thermistors, coarse sun sensor, cup cone, laminated substrate board, aluminum honeycomb structure, Kapton layers, diodes and resistors.

The Proto-flight solar array panel, approximately 7-ft square by 2-in. thick, was an actual flight hardware spare solar array panel and could be used for flight if needed. The panel contains over 2500 silicon solar cells mounted on one side (Fig. 16) with the solar cell string circuitry mounted on the other side (Fig. 17). The panel weighs approximately 22 lb. The components used to build the panel and their location were based upon the DVT test results.

2.5 TEST SPECIFIC HARDWARE

2.5.1 DVT TEST HARDWARE (PHASE 1)

The representative scrap panel was mounted in the 7A Chamber by using a 21-in square by 1/8-in. thick aluminum frame. Each corner of the panel was attached to the corners of the frame using stainless-steel gage wire. The panel was positioned in the center of the chamber, suspended 11 in. above the lamps.

The DVT solar array panels were mounted into the 7A Chamber together. Each panel was mounted in a 1/4-in. tubing square frame, 21-in. square by 3-in. wide. Each corner of a panel was attached to the frame's corners using stainless-steel springs. The panels were centered in the chamber, suspended 11 in. above the lamps. The frame and springs were wrapped with several layers of aluminized Mylar.

The DVT panels were inspected with an extended arm microscope before and after each thermal cycling test. The microscope and table were setup adjacent to the test cell (Fig. 18).

2.5.2 PROTO-FLIGHT TEST HARDWARE (PHASE 2)

A panel handling frame and IR inspection station were provided by TRW and shipped to AEDC prior to test. Both handling frame and IR inspection system were setup and used in the 10V Class 10,000 clean room. Precautions were taken to meet clean room standards. The handling frame consisted of three sections; a square mounting frame and two connecting wheel bases. The Proto-flight solar panel arrived mounted in the square frame. The two wheel bases connected together to support the square frame to provide rotation and mobility of the solar panel (Fig. 19).

The IR inspection station consisted of an aluminum boxed frame approximately 9 ft tall by 9 ft wide by 3 ft deep. Nine-ft horizontal and vertical ball screws with motors were attached to the frame to provide a moving IR camera system for solar panel inspection. An IR camera and a tungsten lamp source were mounted to the ball screws. A 4X magnifying lens was used to visually inspect the Proto-flight solar cells (Fig. 20). The position motors were controlled from a cabinet which housed a motion control system and a video monitor. A VCR was placed in the cabinet to record the visual inspection (Fig. 21).

The Proto-flight solar array panel was suspended 13 in. above the IR heat lamp array using a stainless-steel gage wire. A wire was attached to each panel hinge support (four) to a bracket (four) on the chamber's cryo-liner positioned above the lamp array.

2.6 TEST INSTRUMENTATION

2.6.1 7A THERMAL VACUUM CHAMBER INSTRUMENTATION (PHASE 1)

Chamber vacuum was measured, depending on the vacuum level, using two Pirani/Convectron vacuum gages and two Bayard-Alpert ionization gages. All vacuum gage outputs were computer logged and manually recorded in the test operation log book. Bayard-Alpert gauges were mounted on the northwest side and top of the chamber. Convectron gauges were mounted on the east side turbopump foreline and bottom of the chamber.

Pressure in the chamber's enclosure was measured with a tubulated Bayard-Alpert ionization gauge and was on the order of $3x10^{-7}$ torr. This pressure was more representative of that which existed between the radiation shield and the outer shell of the chamber than that which existed near the DVT panels inside the radiation shield. Based on the temperature difference between the glass envelope of the Bayard-Alpert gauge and the environment inside the radiation shield (~10 K), the pressure near the DVT was on the order of $5x10^{-8}$ torr.

A Kaye Instruments Digi 4S data logger with a 16 channel multiplexer was used to measure the chamber housekeeping data (Fig. 5). The data logger output was sent to and stored on a personnel computer (PC). The log interval was 5 min. All test data files were backed-up on 3-1/2 in. floppy disks.

Chamber surfaces and test article temperatures were measured using Teflon insulated type T (copper/constantan) thermocouples read by the data logger. The data logger converted the thermocouple output voltages to temperatures displayed in °C. Two thermocouple feed throughs and two lamp feed throughs were installed in a single port on the east side of the chamber. Thermocouples were mounted on the chamber liner, lamp reflectors, lamp frame, test article support frame and the DVT panels.

Each thermocouple location on the test chamber was verified by spraying the thermocouple junction with a "Tech Spray" solution for a temperature response. A calibration was made on the data system using an ice bath reference temperature and a calibrated voltage standard representing elevated temperatures. The data logger had a $\pm$0.1°F resolution. A major potential source of error with temperature sensors is poor thermal contact. To avoid such problems, all thermocouples were attached with a Bellville washer to provide a spring-loaded contact.

A type T jumper wire from the Kaye data logger to NASA-MSFC HP3852 provided dual logging and over/under temperature safety controls. The HP3852 controlled the off/on of the lamps using a relay contact based on the average temperature of the DVT panels. The NASA-MSFC/TRW's test hardware included a continuity monitoring system, power supplies, two temperature controllers, patch panel, PC and wide carriage printer, and HP3852 data logger as shown in Fig. 5.

To minimize the effects of any possible power interruptions (particularly on the long term stability tests), the vacuum pumping and data handling systems were powered from a 50 kW uninterruptible power supply. If a power failure occurred, the isolation valve between the vacuum pump and the chamber automatically closed. To further protect the DVT hardware from contamination, a protection circuit was used to close the isolation valve if turbomolecular pump rotation speed fell below its normal level.

2.6.2 10V THERMAL VACUUM CHAMBER INSTRUMENTATION (PHASE 2)

Chamber vacuum was measured, depending on the vacuum level, using several Baritron vacuum gages and Bayard-Alpert ionization gages located at various places around the chamber. All vacuum gage outputs were computer logged and manually recorded in the test operation log book. All chamber surface temperatures were measured by CLTSs, similar to RTD devices and were bonded to the liner with a thermally conductive epoxy. A PC-based data system was used to measure the chamber housekeeping data. The data logger output was recorded by a personal computer (PC). The log interval was 5 min. All test data files were backed-up on 3-1/2 in. floppy disks.

The test article temperatures were measured using Teflon-insulated type T (copper/constantan) thermocouples read by NASA-MSFC/TRW's HP3852 data logger. The data logger converted the thermocouple output voltages to temperatures displayed in °C. All lamp controls and thermocouple feed throughs were installed in a single port on the bottom west side of the chamber. Various thermocouples were mounted on the lamp reflectors, lamp frame, and the Proto-flight solar array panel.

Each thermocouple location on the Proto-flight solar array panel was verified by spraying the thermocouple junction with a "Tech Spray" solution for a temperature response. A major potential source of error with temperature sensors is poor thermal contact. To avoid such problems, all thermocouples were attached with a thermally conductive epoxy onto the Proto-flight solar array panel.

The NASA-MSFC HP3852 controlled the off/on of the lamps using a relay contact based on the average temperature of the Proto-flight solar array panel. The HP3852 also provided redundant over/under temperature safety controls. The NASA-MSFC/TRW's test hardware included a continuity monitoring system, power supplies, patch panel, PC and wide carriage printer, and HP3852 data logger as shown in Fig. 22.

An uninterruptible power supply was used to minimize the effects of any possible power interruptions on the test, the vacuum pumping, and data handling systems. If a power failure occurred, the isolation valve between the vacuum pump and the chamber automatically closed.

3.0 PROCEDURE

3.1 DVT SOLAR PANEL ARRAYS TESTS (PHASE 1)

AEDC used the 7A Thermal Vacuum Chamber, 3 kW GHe refrigeration system and IR heat lamps to thermally cycle the DVT solar array panels. The chamber liner was cooled and maintained to a specified temperature while the DVT solar array panels were thermally cycled by turning the IR heat lamps off and on. This method allowed the DVT solar array panels to be environmentally tested at simulated space conditions.

Prior to the thermal cycling tests, a checkout pumpdown of the 7A Thermal Vacuum Chamber was conducted to establish functionality and performance of key test systems. The objectives were to determine the 3 kW refrigeration response and capacity, IR lamp voltage setting, solar panel thermal response time, and cycle time of a representative scrap panel. Other objectives were to bakeout the test chamber, verify AEDC and NASA-MSFC/TRW instrumentation data system operation and over-temp safety systems.

Upon the checkout pumpdown completion, both DVT solar array panels were installed in the 7A Chamber and interfaced to AEDC and NASA-MSFC data acquisition system. The 153 thermal cycles were broken down into three separate chamber pumpdowns at cycles 1-8, 9-89, and 90-153. Cycles 1-89 represent the entire 5 year orbital mission. Cycles 90-153 represent an additional 5 years of flight. Once proper operation was verified, the chamber was evacuated and the solar panels underwent thermal cycles 1-8 with panel temperatures ranging from 72°C to -201°C. The chamber GHe liner was maintained at less than -201°C while IR heat lamps were turned on and off to control the panel's temperature. The solar panel's temperatures ranged from

62°C to -191°C for thermal cycles 9-89 and 90-153. Each thermal cycle, excluding the first (estimated at 8 hr), was estimated at 3 hr with a total of eight cycles per day. Figure 23 shows the projected thermal cycling model in the 7A Chamber. Upon each series of thermal cycles, the panels were removed and transported to TRW in Redondo Beach, CA for visual inspection and flash testing (estimated 4 days). The thermal data acquired on NASA-MSFC's data acquisition system were transmitted via internet to NASA-MSFC at Huntsville, AL and TRW at Redondo Beach, CA. Housekeeping data acquired by AEDC were processed and shipped to NASA-MSFC.

3.2 PROTO-FLIGHT SOLAR PANEL ARRAY TEST (PHASE 2)

Upon Proto-flight solar array panel delivery to AEDC, NASA-MFSC personnel inspected the solar panel in the 10V clean room using the NASA-MFSC/TRW provided IR inspection station. The Proto-flight solar array panel was then installed in the 10V Thermal Vacuum Chamber and interfaced to NASA-MSFC data acquisition system. Once proper operation was verified, the chamber was evacuated and the solar array panel underwent 11-1/2 thermal cycles with the temperatures ranging from 62°C to -196°C. Each thermal cycle, excluding the first (estimated at 12 hr +27 hr), was estimated at 12 hr. The chamber requires 27 hr for evacuation and cool down of the cryo-liner. The first two thermal cycles were used to determine the operating parameters of the 3 kW refrigeration response and capacity, IR lamp voltage setting, Proto-flight solar array panel thermal response time, and to validate the NASA-MSFC's projected Proto-flight thermal cycling time, and checkout NASA-MSFC's data acquisition system. Test conditions were provided at less than 1E-5 torr vacuum and a thermal background temperature of less than -196°C to simulate flight conditions. Figure 24 shows the projected NASA thermal cycling model for the 10V Chamber. Upon completion, the Proto-flight solar array panel was re-inspected and shipped to TRW in Redondo Beach, CA for further inspection. The thermal data were acquired on NASA-MSFC data acquisition system and delivered to NASA-MSFC at Huntsville, AL and TRW at Redondo Beach, CA. Housekeeping data acquired by AEDC were processed and shipped to NASA-MSFC.

4.0 RESULTS AND DISCUSSION

4.1 DATA PRESENTATION

Within each hardware configuration, the tests were conducted in the order that best used the test time available. All test procedures and events of the test chambers and test articles during test programs were recorded and stored in the AEDC Project 2538 (Phase 1 and 2) AXAF-I Test Log Book.

4.2 DVT SOLAR PANEL ARRAY TEST (PHASE 1)

4.2.1 CHECKOUT PUMPDOWN #1

A bakeout of the 7A Thermal Vacuum Chamber and all materials in the chamber was performed one week prior to the checkout test for 24 hr at 160°C under vacuum.

A checkout pumpdown of the 7A Thermal Vacuum Chamber was performed using the scrap panel for the test article. It was determined by this test that 70 V applied to the IR lamps produced the required heating on the panel without exceeding the maximum cycle temperature. The instrumentation and data system checked out with minimal problems.

The thermal cycling model required the test article to undergo a 1-hr bakeout (110°C) before cooling was applied. The 3 kW refrigerator was pre-cooled in the by-pass mode prior to test article hot soak in hopes of reducing the GHe liner cool down time. However, the result created a situation similar to a fuel line vapor lock. The cold gas was fed into the hot liner which stalled until the cold gas worked through the system. The typical 7A Chamber cool down is 4 hr starting with a room temperature liner. Heating the chamber to 110°C and having the refrigerator system in bypass mode increased the cool down to 8 hr. The allotted cool-down period was estimated at 8 hr.

The thermal cycling time of the scrap panel from 72°C to -201°C was 8 plus hr compared to the 3.5 hr predicted. It was concluded that the IR lamp's cool-down temperature lagged well behind the chamber's liner. This caused a delay in the scrap panel's radiative cooling. The panel was removed for chamber hardware modifications.

4.2.2 DVT SOLAR PANEL TEMPERATURE CYCLING 1-8

Reduction of the liner temperature cool-down time during the second pumpdown was successful by cooling down the GHe liner along with the 3 kW refrigerator system. The result was a decrease from 8 hr to 4 hr.

Active GHe cooling lines were added to the lamp array frame in an attempt to rapidly cool the lamps. Also, the lamp reflectors were cold sunk to the lamp frame using brass shims. All of the instrumentation and lamp wiring was thermally shorted to the chamber's liner and further wrapped with several layers of aluminized Mylar. All of the lamp frame, support frame, and test article supports were wrapped with multiple layers of aluminized Mylar.

A complete visual inspection was made on the DVT solar array panels before installation in the 7A Chamber. Four acceptable glass cracks had occurred during shipping and were documented on the solar panels road map.

The panels underwent a 1-hr hot soak at 110°C and thermal cycled from -201°C to 72°C for eight cycles. Each thermal cycling was approximately 3.5 hr (Fig. 25). The instrumentation and data systems worked without any problems. The chamber pressure, however, increased and decreased as the thermal cycles were executed. The chamber pressure based-out on the middle 10^{-6} torr scale after the cryo-liner was completely cold (10 K). The chamber pressure decreased to the lower 10^{-7} torr scale when the lamps were turned on and the average temperature of the liner was above 40 K. Similar pressures were noted for each thermal cycle.

The DVT solar array panels were visually inspected after removal, finding only one additional cover glass crack which propagated from a previously discovered glass chip. The DVT panels were shipped to TRW for flash testing.

4.2.3 DVT SOLAR PANEL TEMPERATURE CYCLING 9-89 PART 1

The DVT solar array panels were re-installed in the 7A Chamber to continue the second series of cycling, 9-89. The panel's first and second cycle time had increased to 5 plus hr each. The time had increased from the first eight cycles and more than the estimated TRW time model.

The chamber was re-opened for examination to investigate any changes that may have occurred. As a result, a few Mylar wraps were tightened and more Mylar was added to the cable feed through on the liner. It was determined that in the previous 1-8

thermal cycles, that a very small amount of GHe was leaking into the chamber during the cold soak of the cycles which decreased the cooling time. This explained the chamber pressure fluctuations during the 1-8 cycles.

4.2.4 DVT SOLAR PANEL TEMPERATURE CYCLING 9-89 PART 2

The chamber was closed out to continue the thermal cycling with the increased cycling time. The 3 kW refrigerator and IR lamp operation worked very well. The lamp power supplies were manually set at 70 volts which allowed the solar panels to ramp up to the desired temperature in 20 min and maintain the temperature for an additional 10-min hot soak. The cycling times were consistent with each cycle. Eighty-one thermal vacuum cycles from -191°C to 62°C were completed. The DVT solar array panels had completed a total of 89 thermal cycles which represented the entire AXAF-I 5 year mission.

A thermistor on panel s/n 001 showed signs of an open-circuit after the 17th cycle. After the cycling was complete, the DVT solar array panels were visually inspected finding the thermistor's lead wires were not stressed relieved as the other panel. Inadequate stress relief on the thermistor's wiring may have contributed to the failure. The DVT panels were shipped to TRW for flash testing. The flash testing preliminary report stated that the DVT's electrical output after the 5 year simulated orbital cycling had minimal electrical degradation.

4.2.5 DVT SOLAR PANEL TEMPERATURE CYCLING 90-153

The DVT solar array panels were loaded back into the 7A Chamber for the remaining 64 thermal cycles. The remaining thermal cycles represented an additional 5 years in orbit. The thermal cycle temperature limits were changed to represent the orbital thermal model to decrease the amount of test time as shown in Table 1.

Upon completion, the DVT solar array panels were removed from the 7A Chamber for final inspection. As a result, a large number of solar cells on each panel had slightly lifted from the panel. All of the electrical strings were not effected and none of the cells had completely come loose from the substrate.

The DVT panels were shipped to TRW for flash testing and further visual inspection. The preliminary report stated that there was an insufficient amount of epoxy used during the solar cell lay down.

4.3 PROTO-FLIGHT SOLAR ARRAY TEST (PHASE 2)

A bakeout of the 10V Thermal Vacuum chamber and all materials in the chamber was performed one week prior to test for 24 hr at 130°C under vacuum.

Upon arrival to AEDC, the Proto-flight solar array was inspected for initial changes using the NASA-provided IR inspection station. The changes were noted by a TRW technician. The Proto-flight panel's four hinge points were suspended from the chamber liner using stainless-steel gage wire at four separate locations in 10V chamber. The panel was centered and mounted 13 in. above the IR heat lamp array (Fig. 26). All of the thermocouples and solar cell string wiring were connected and checked out prior to chamber close-out. The chamber was evacuated after all of the operation systems were checked out. The first cycle included a 1-hr hot soak at 110°C. The hot soak was interrupted by a local area tornado. All lamps were shut down and the chamber was held on-line until the storm had passed, approximately 2 hr. The lamps were placed back on-line and the testing resumed.

The 3 kW refrigerator was brought on-line after the hot soak was completed. The refrigerator was cooled down with the chamber dictated from lessons learned of the DVT panel test. The chamber and panel cool down was estimated at 32 hr. The actual time was just over 21 hr. The second and third cycle required the panel's temperature to be elevated to 122°C for 10 min. The second cycle had an additional time added to allow a checkout of thermocouple averaging program and reset the maximum temperature from 110°C to 122°C. Cycles 4 to 11-1/2 were from -196°C to 62°C. Figure 27 represents the Proto-flight solar array panel, IR lamps and chamber liner's average temperatures. The estimated time for each thermal cycle was 12 hr. The actual time for each thermal cycle was 3 hours and 45 min. The actual cycle times are shown in Table 2.

Upon completion, the Proto-flight solar array panel was removed from the 10V Chamber for final inspection. As a result, a very few additional glass cracks appeared but no blow-outs had occurred. The Proto-flight solar array panel was shipped to TRW for flash testing and further visual inspection.

5.0 CONCLUDING REMARKS

Based on results of the AXAF-I operational tests, the following should be noted:

1. The 3 kW GHe refrigeration system cools down a hot GHe liner (at 110°C) faster with the refrigeration system initial temperature at ambient. Attempts were made to pre-cool the 3 kW refrigerator in the by-pass mode prior to test article hot soak in hopes of speeding the GHe liner cool-down time. However, the result created a situation similar to a fuel line vapor lock. The cold gas would feed into the hot liner and stall causing an 8-hr cool-down time. A different attempt was made, during the second pumpdown, by cooling down the GHe liner along with the 3 kW refrigerator system. The time was decreased to 4 hr.

2. Thermal cycling with 10 K background requires active cooling of the lamp array. Cooling the lamp frame and reflectors through heat straps and frame contact to the liner results in panel cool down that is slower. However, the quartz lamps are even slower because their heat can only be removed by radiative cooling. During the DVT testing, the lamp frame and reflectors cooled to the required temperature, but the quartz lamp temperature lagged well behind. The quartz lamp cooling was increased by actively cooling the lamp reflectors and frame.

3. A cold leak can still appear after a thorough leak check on GHe systems. Evidence of a cold leak was indicated during the DVT 1-8 thermal cycles. The chamber pressure increased and decreased as the lamps were operated on and off. The chamber pressure would rise to the middle 10^{-6} torr scale when the lamps were off and the chamber approached 10 K. The chamber pressure would reduce to the lower 10^{-7} torr scale after the lamps were turned on to heat the test article and liner. After the cycles were completed, the inlet and outlet feed line seals were replaced. The condition did not reappear.

4. Lamps at extreme cold temperatures will have little resistance thus causing a large current in-rush. A pre-warm circuit or a current limiting supply should be used in this test configuration.

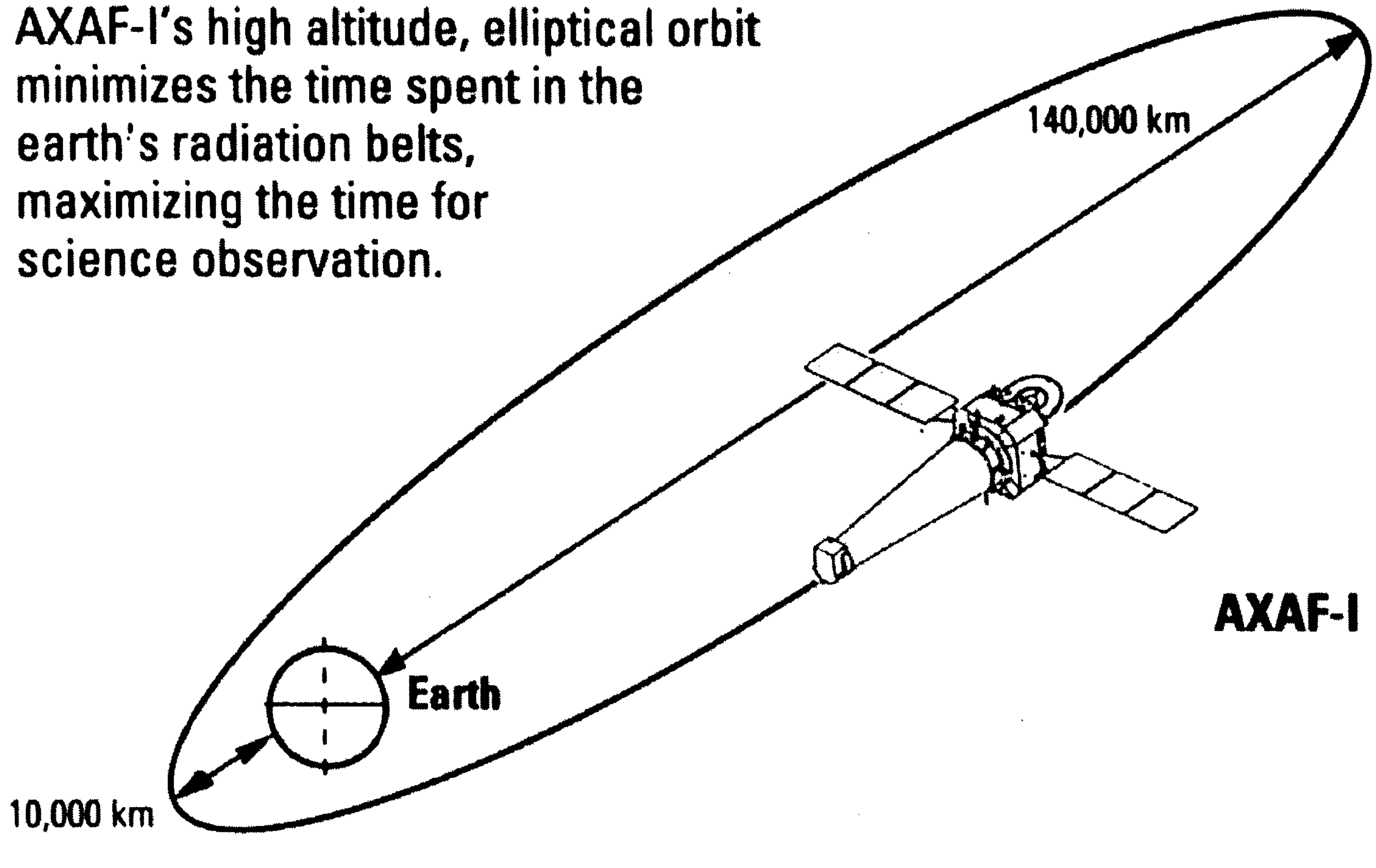

Figure 1. AXAF-I Orbital Flight.

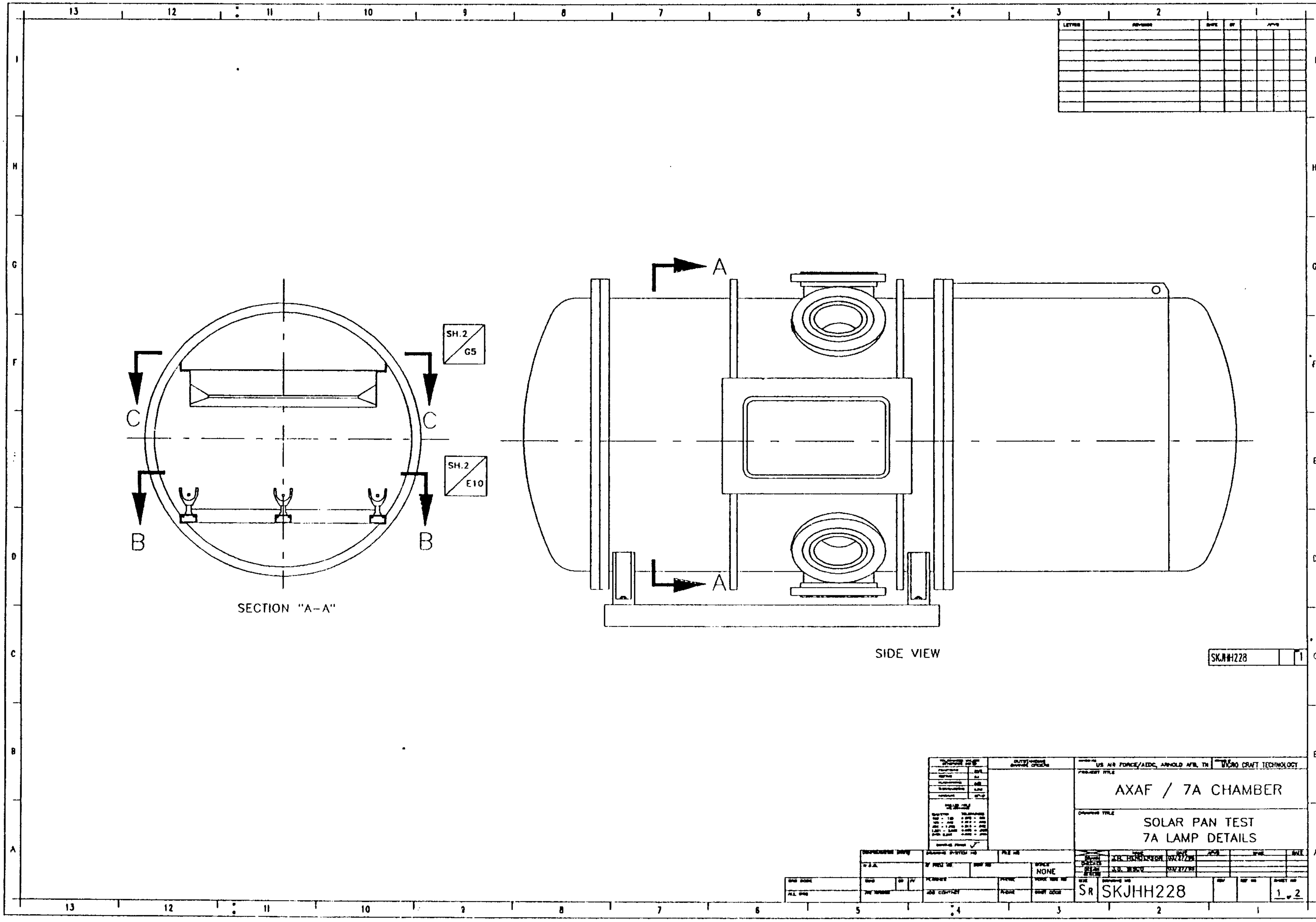

Figure 2. 7A Thermal Vacuum Chamber

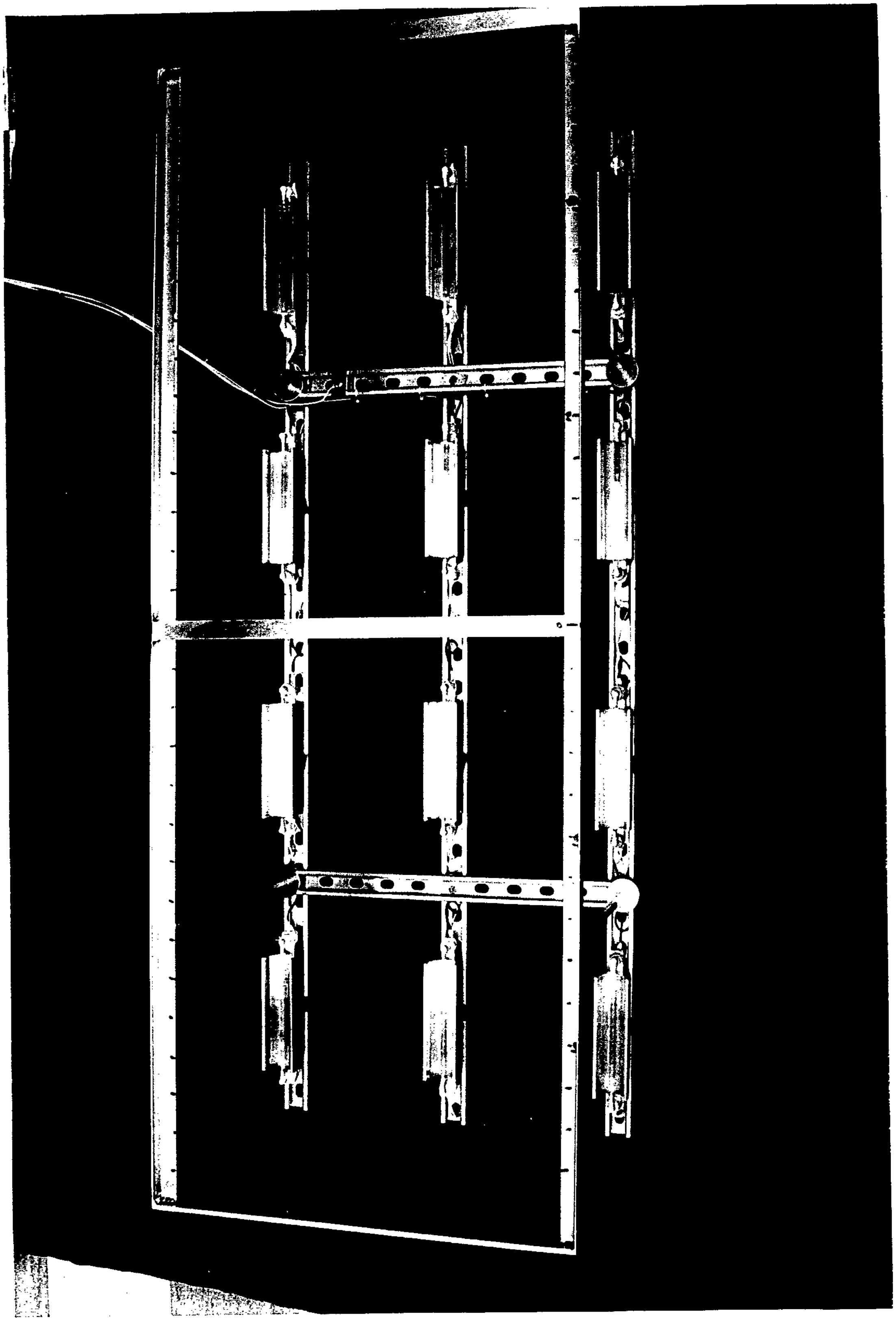

Figure 3. 7A Lamp Array

Figure 4. 7A Lamp Array Wrapped

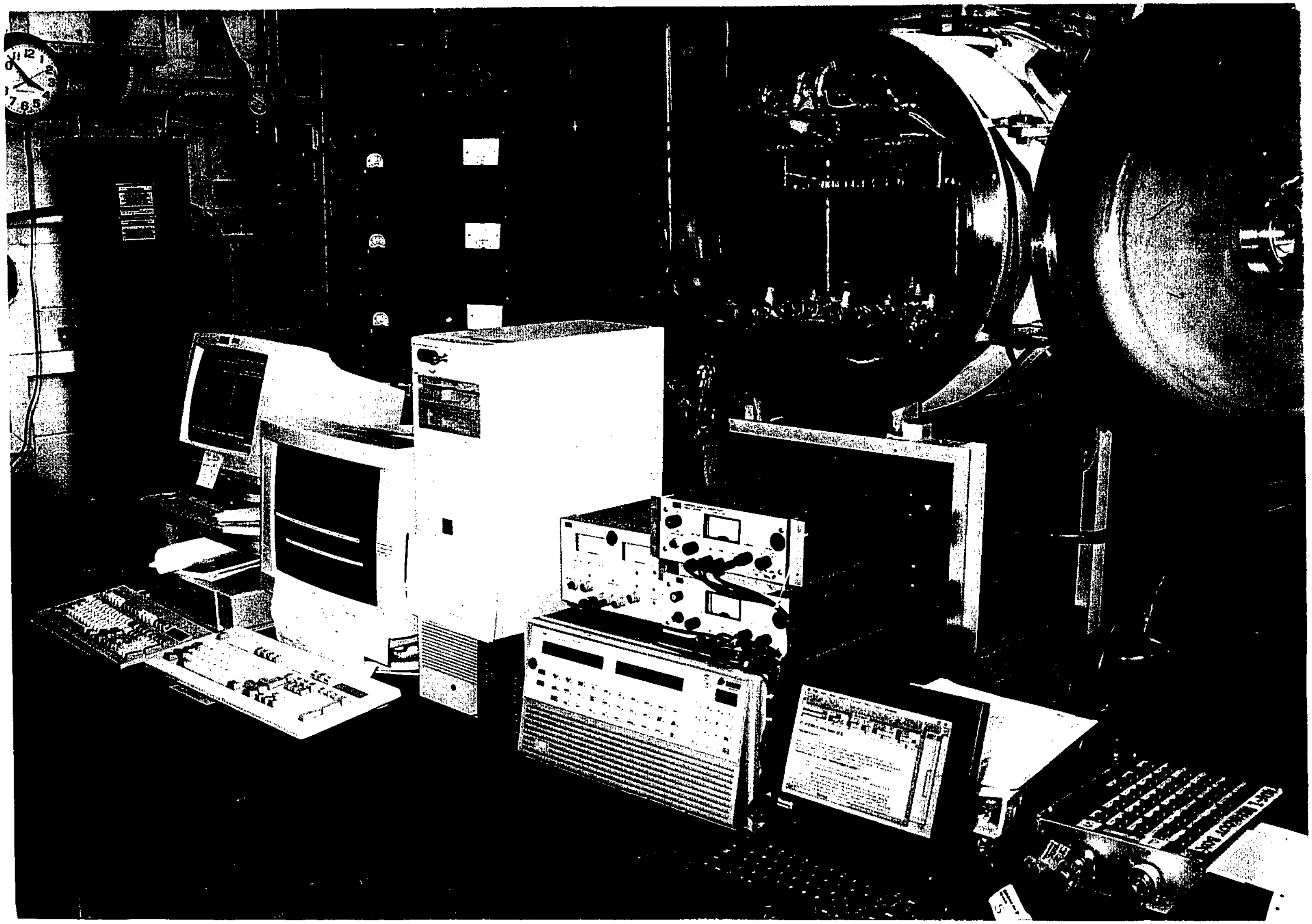

Figure 5. 7A Lamp Controls

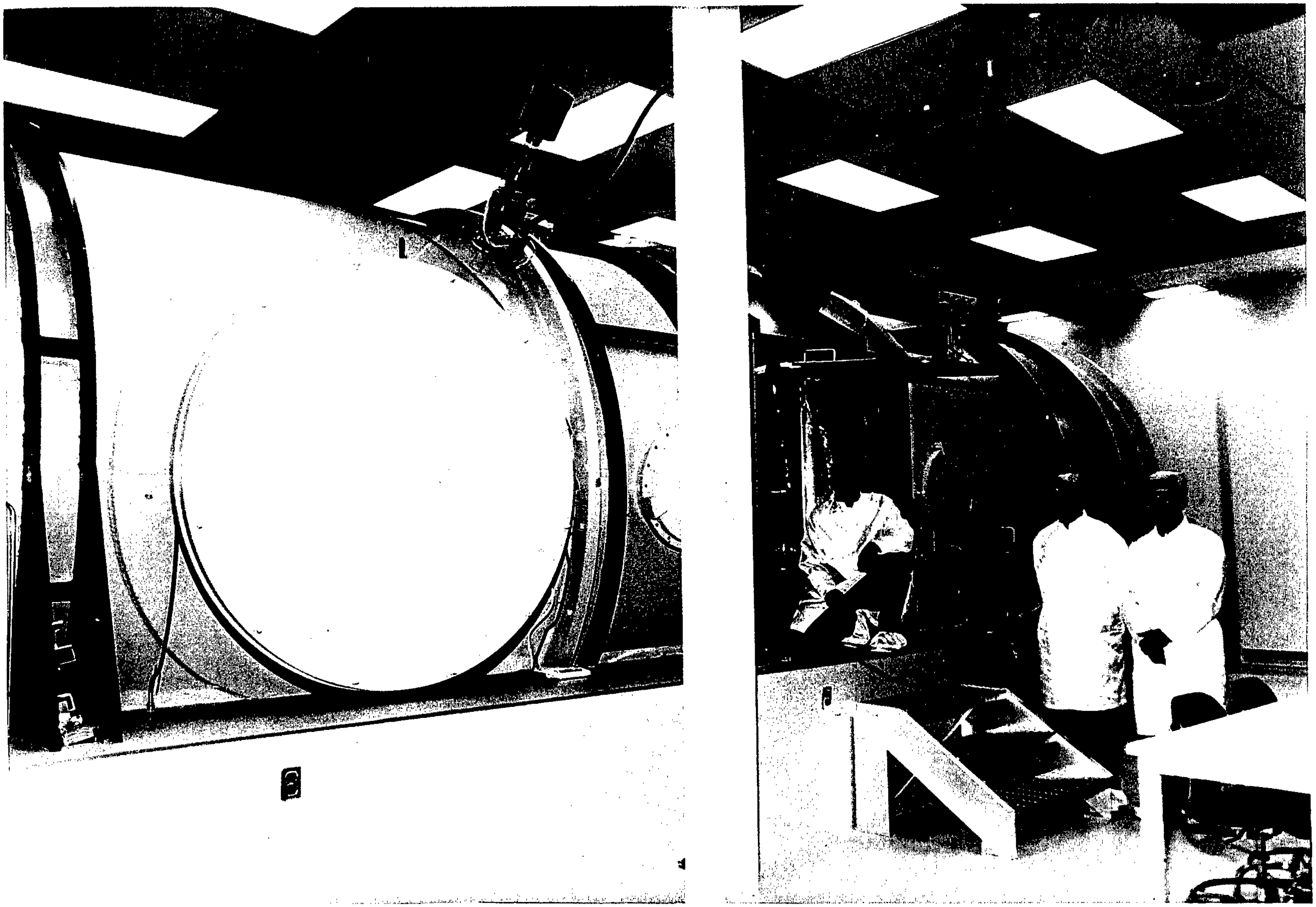

Figure 6. 10V Thermal Vacuum Chamber/Clean Room

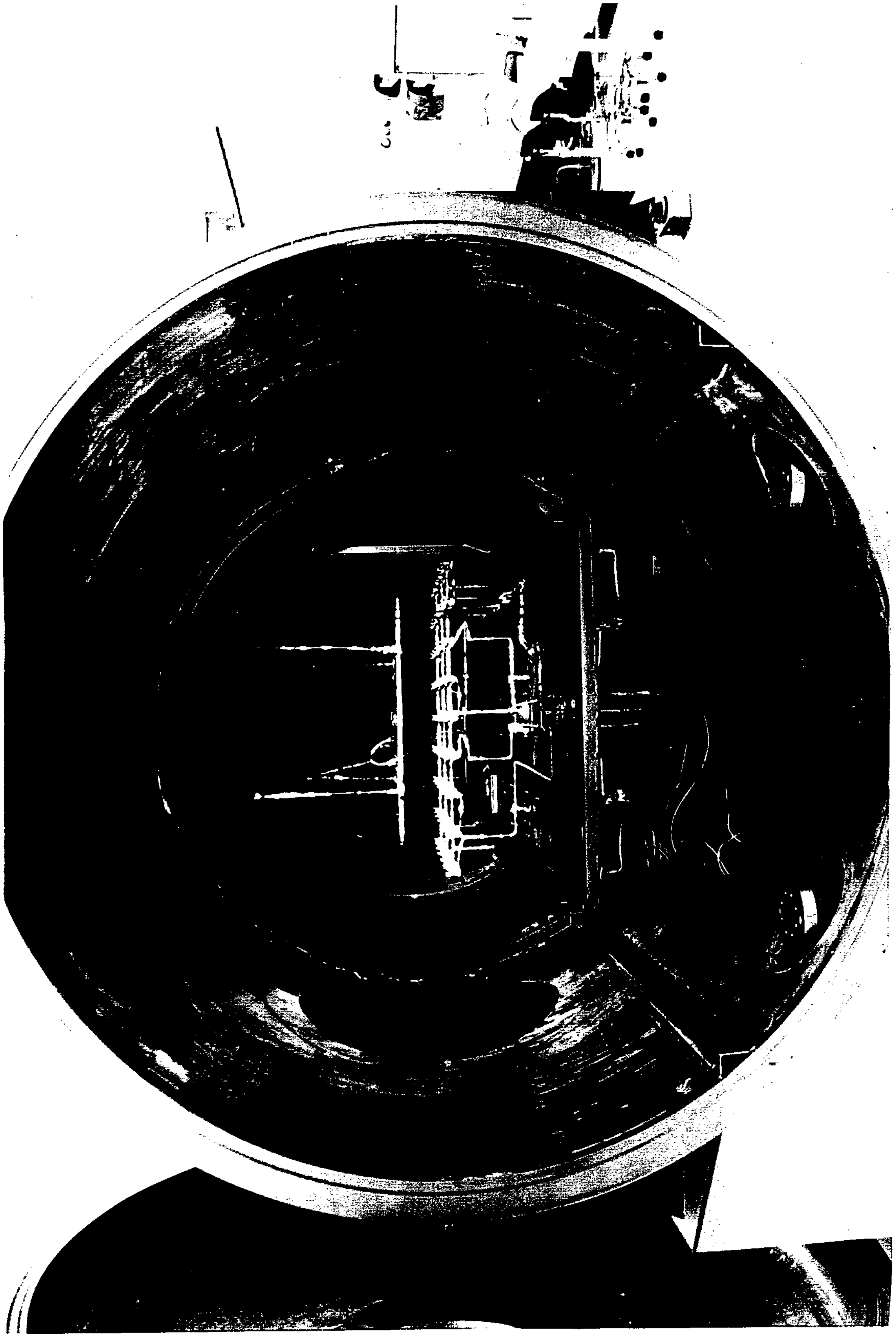

Figure 7. 10V Thermal Vacuum Chamber

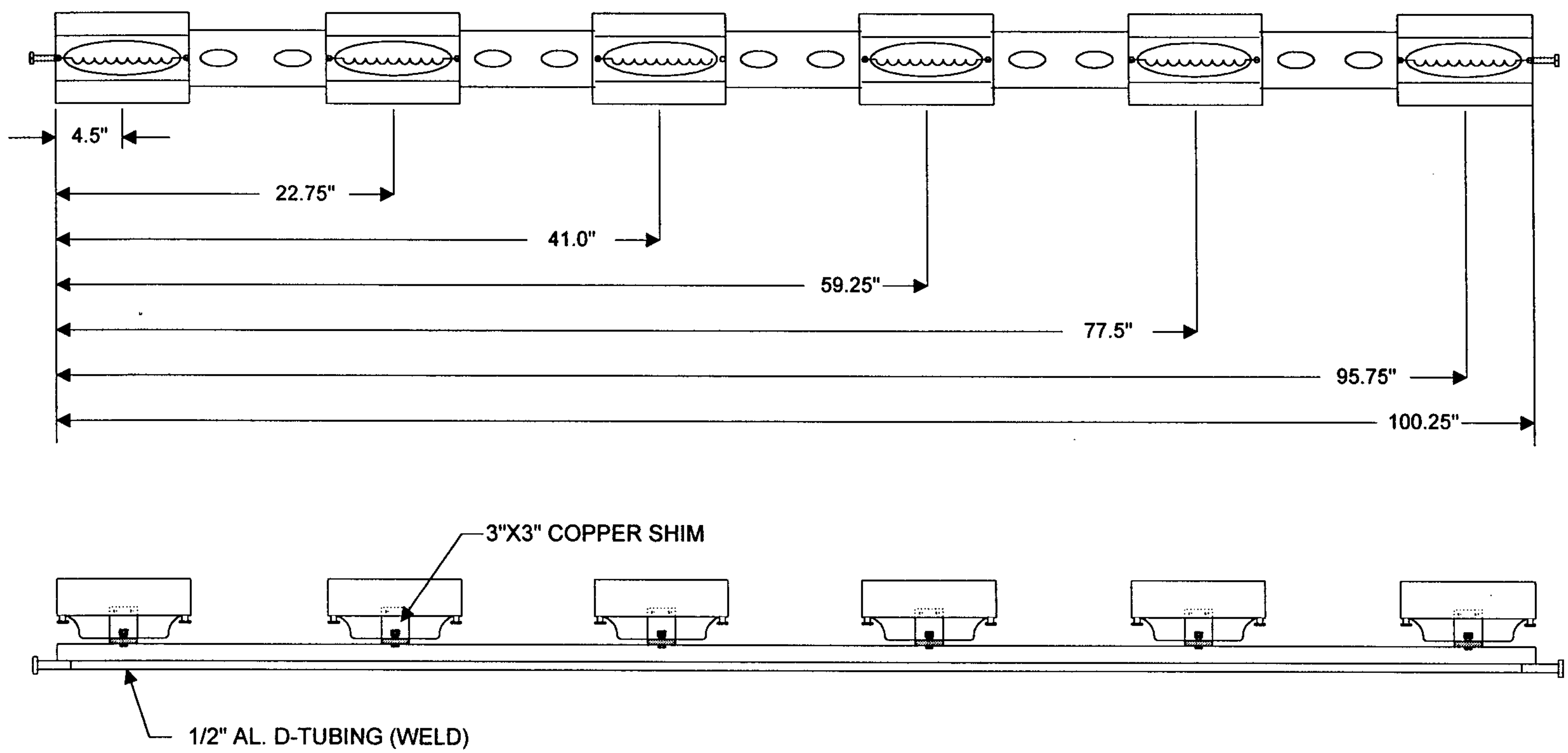

Figure 8. 10V IR Heat Lamp Array

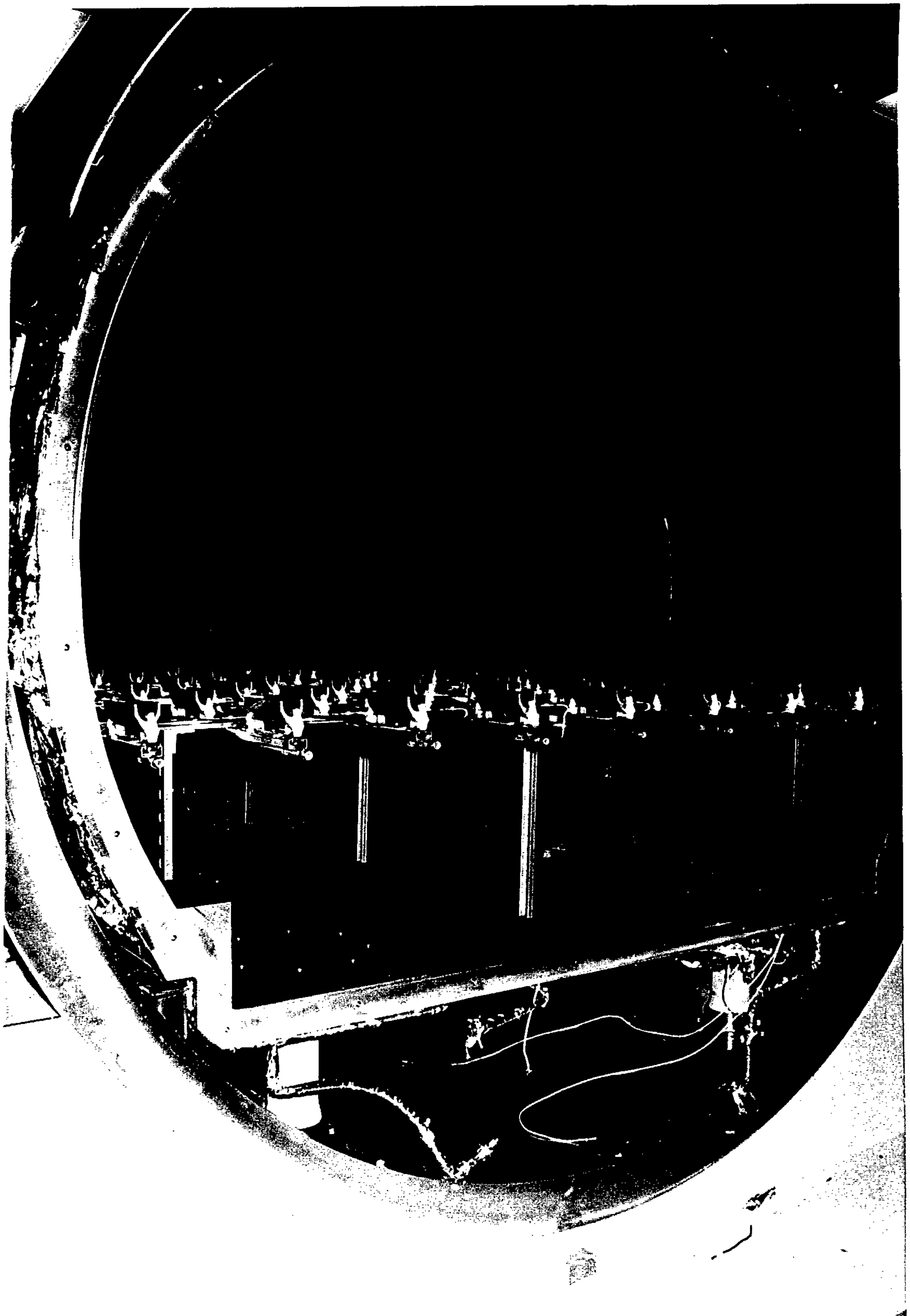

Figure 9. 10V Lamp Array in Chamber

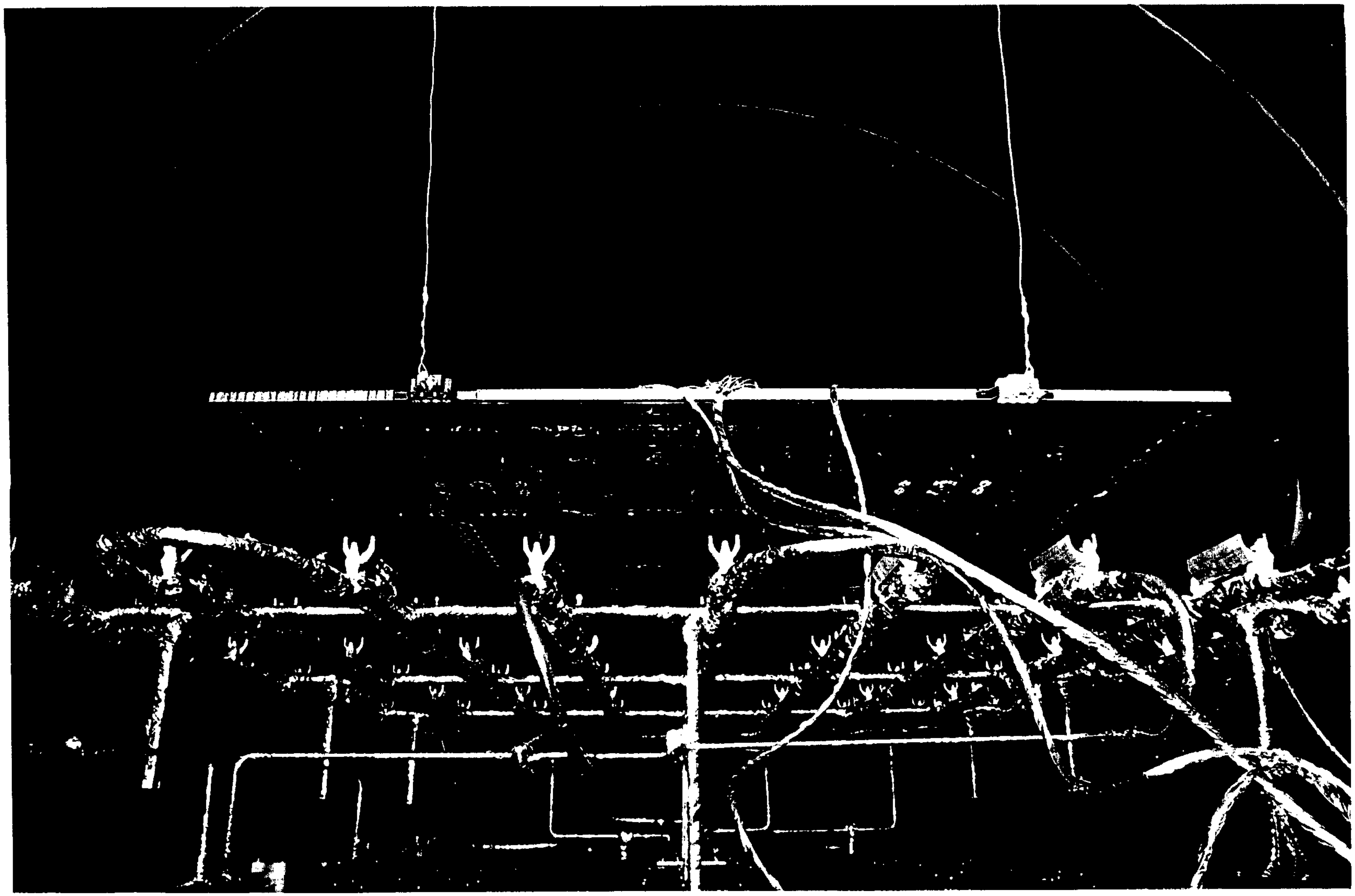

Figure 10. 10V Lamp Array in Chamber/Wrapped

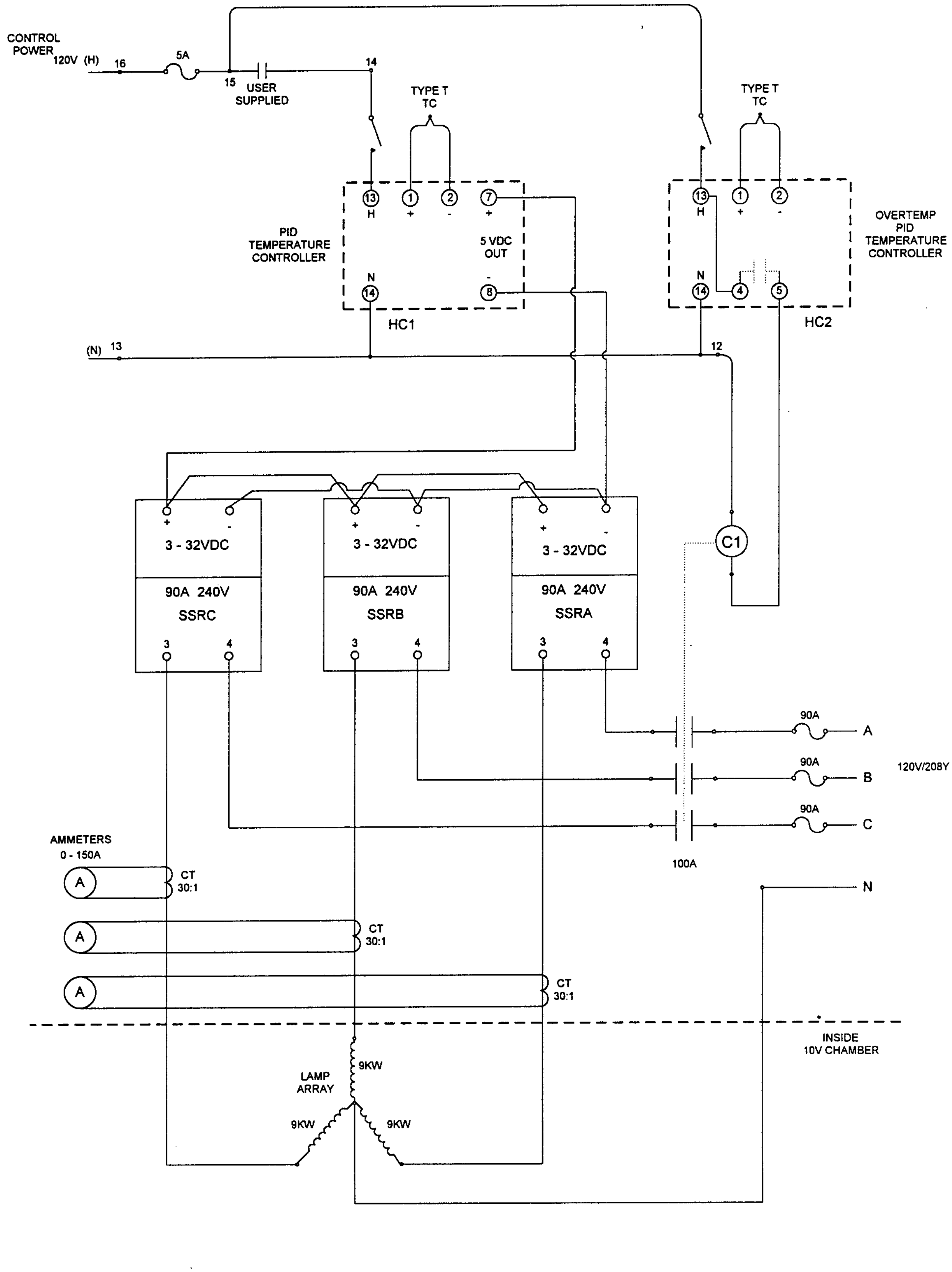

Figure 11. 10V Lamp Array Control and Power Wiring

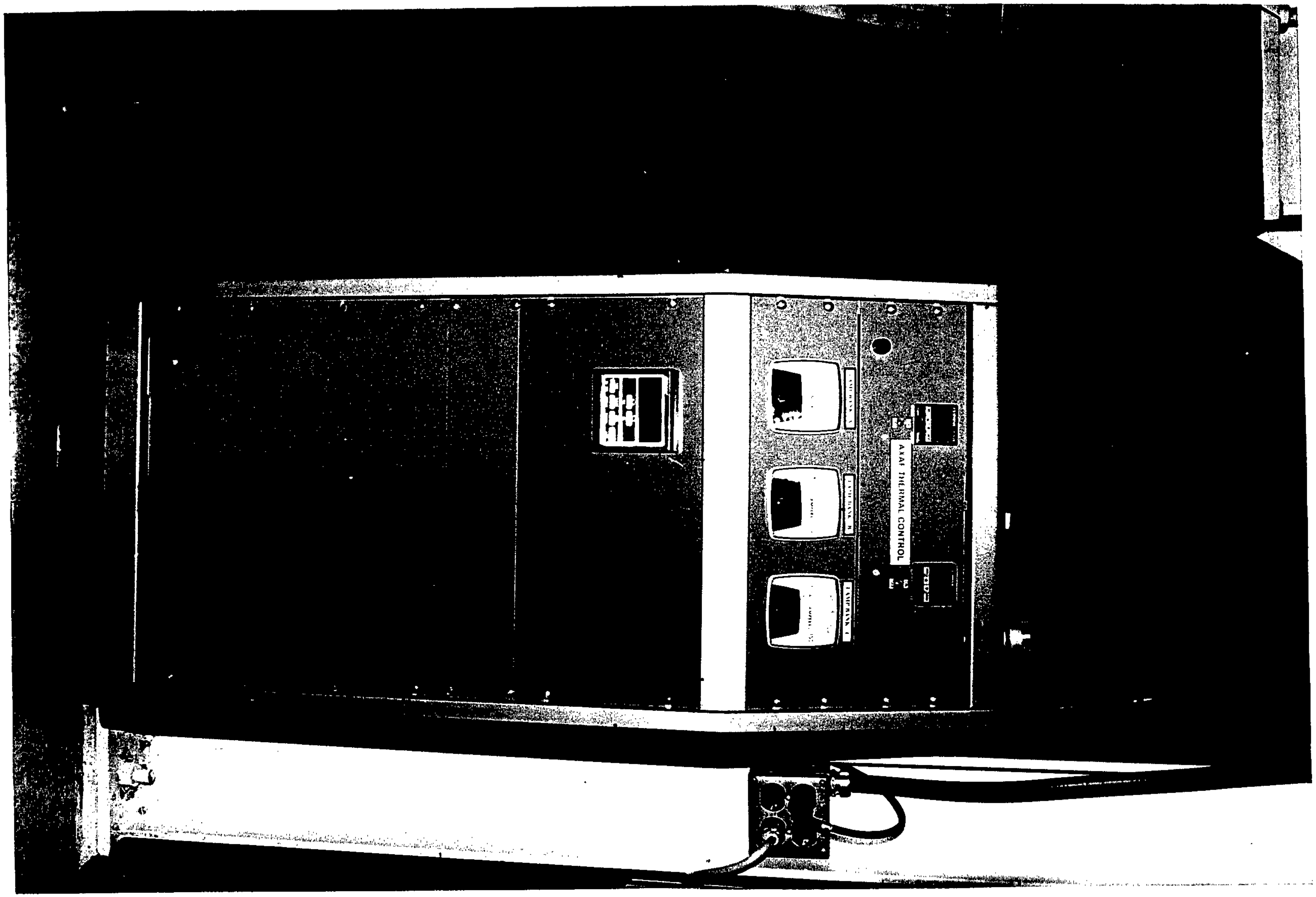

Figure 12. 10V Lamp Controls Unit

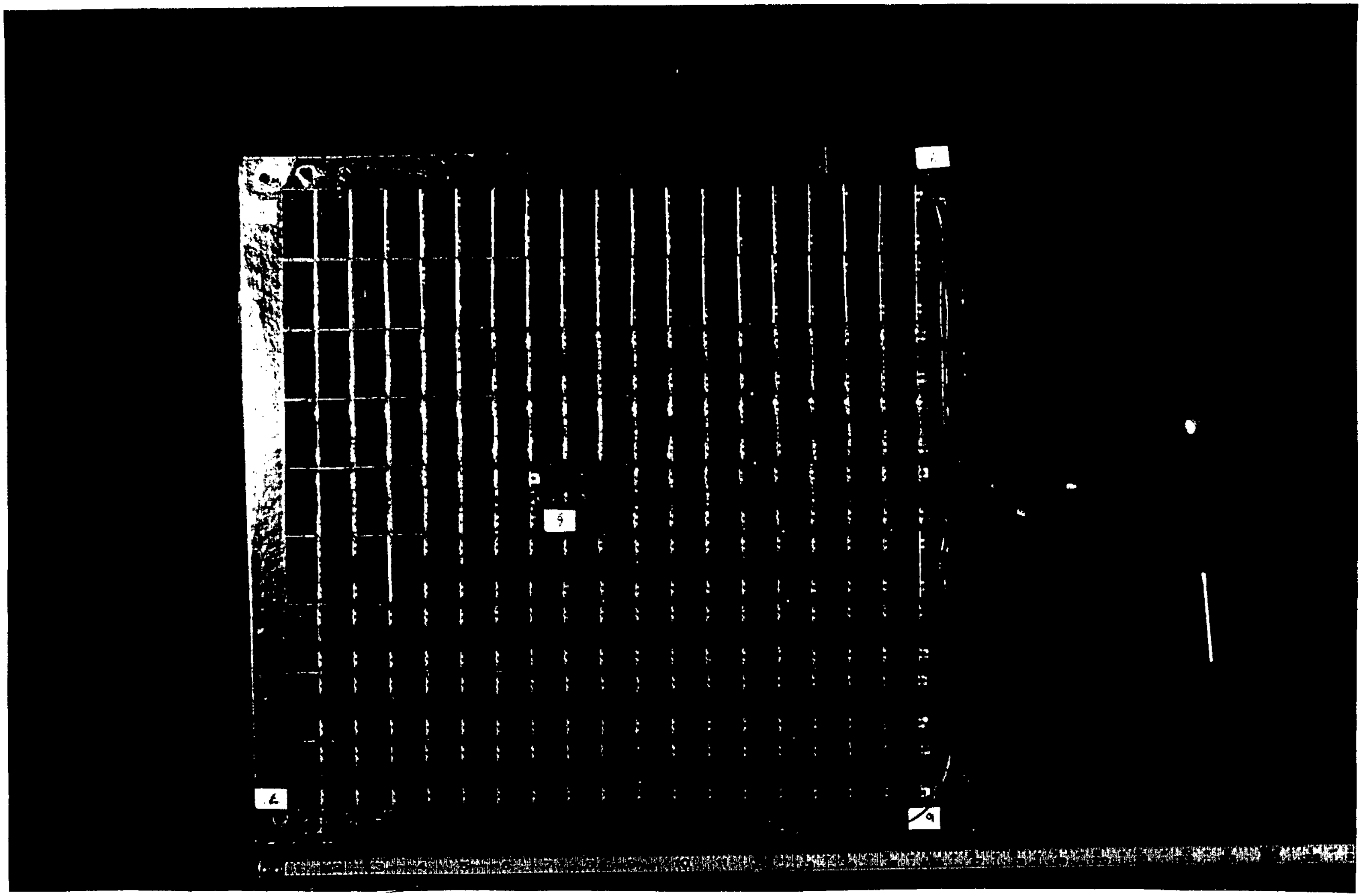

Figure 13. Scrap Panel

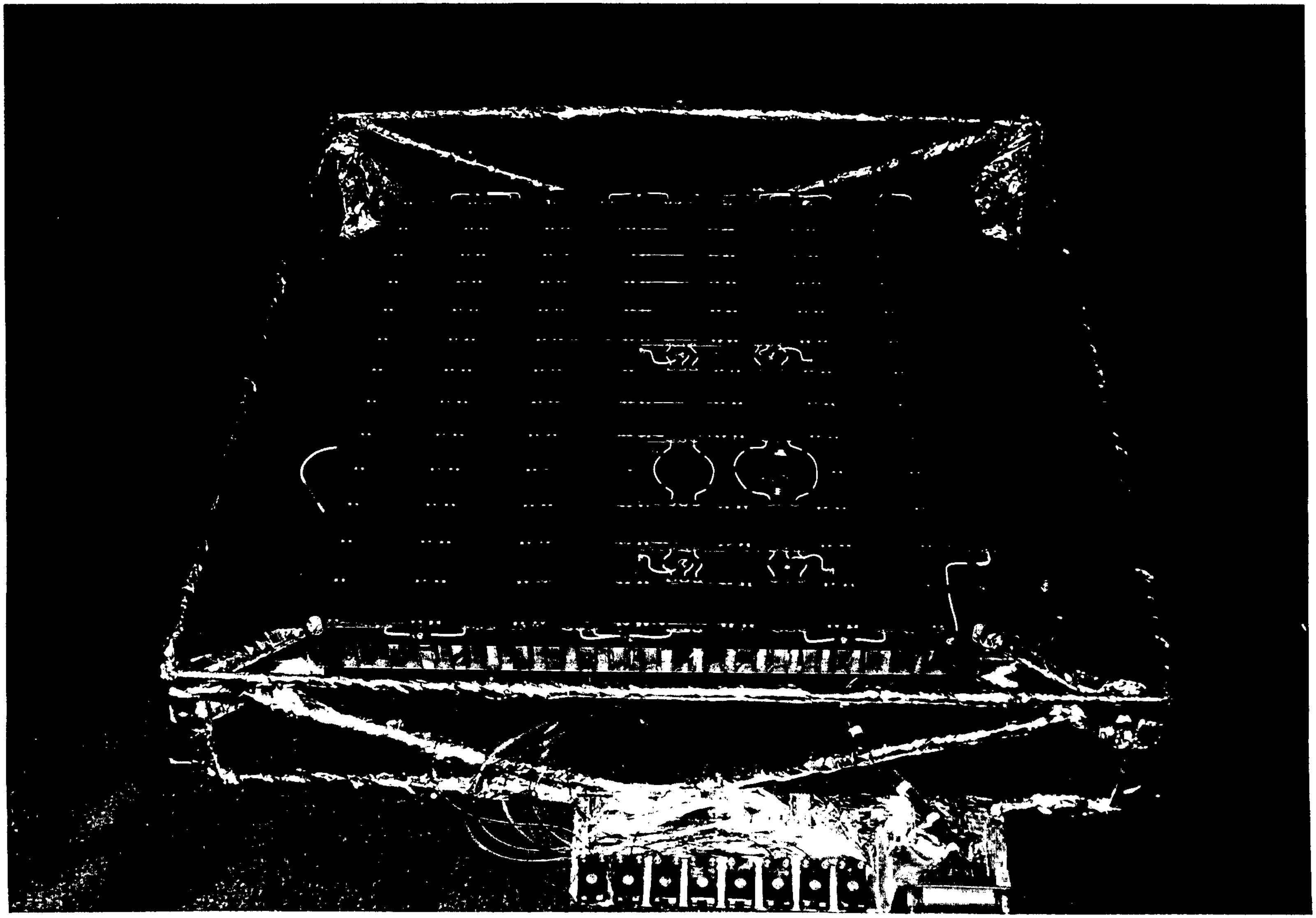

Figure 14. DVT Solar Array Panel - Cell Side

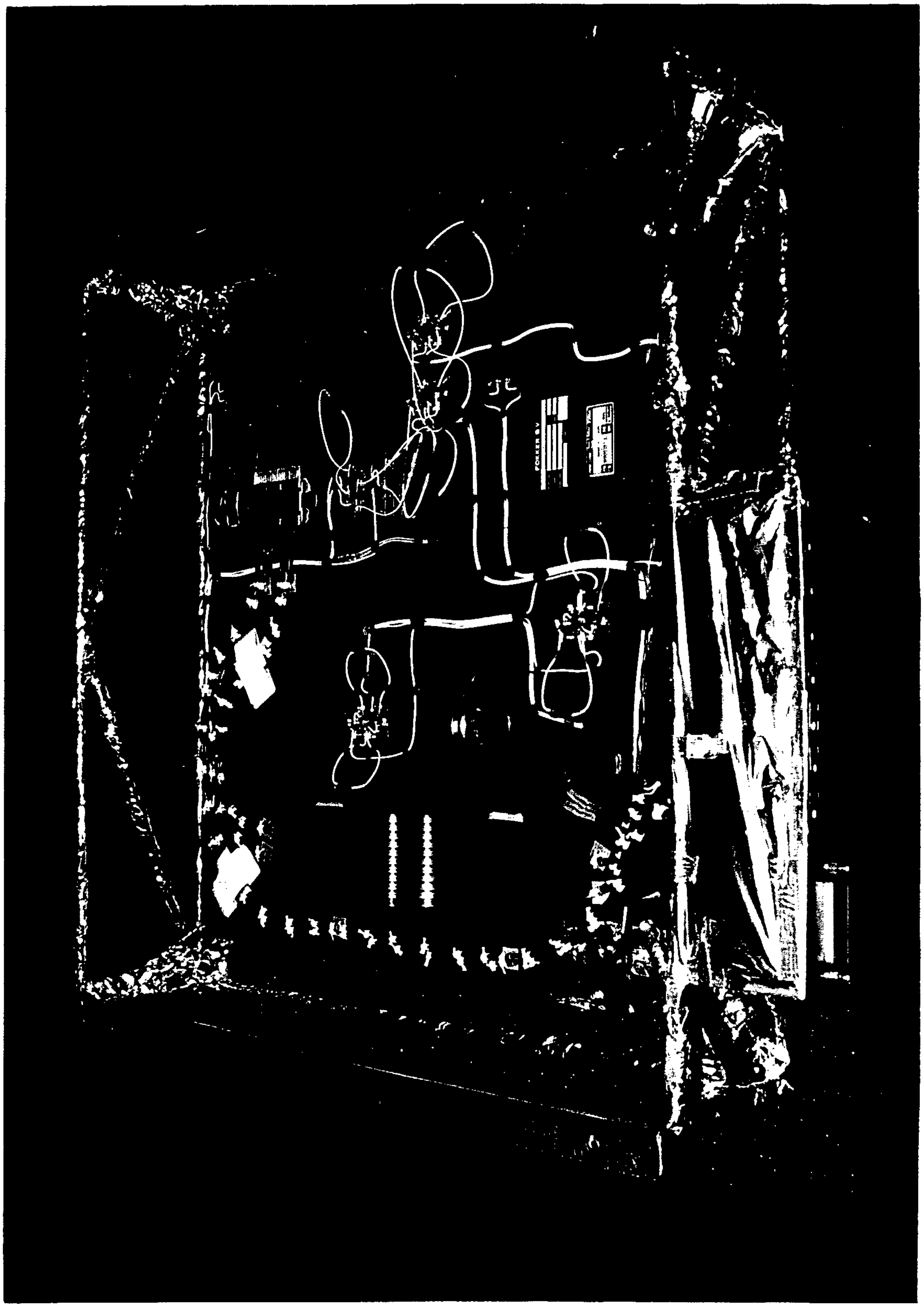

Figure 15. DVT Solar Array Panel - Wire Side

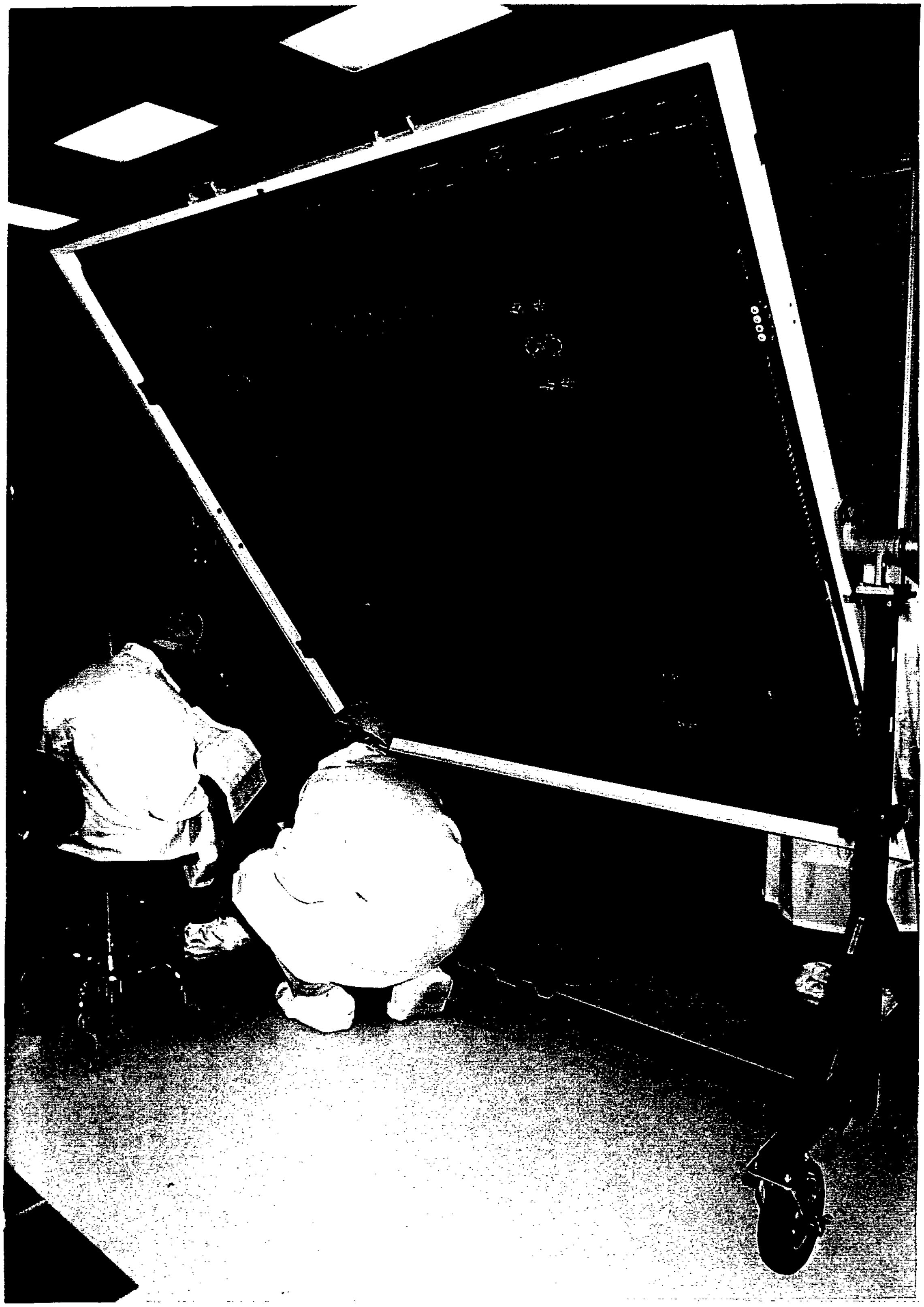

Figure 16. Proto-flight Solar Array Panel - Cell Side

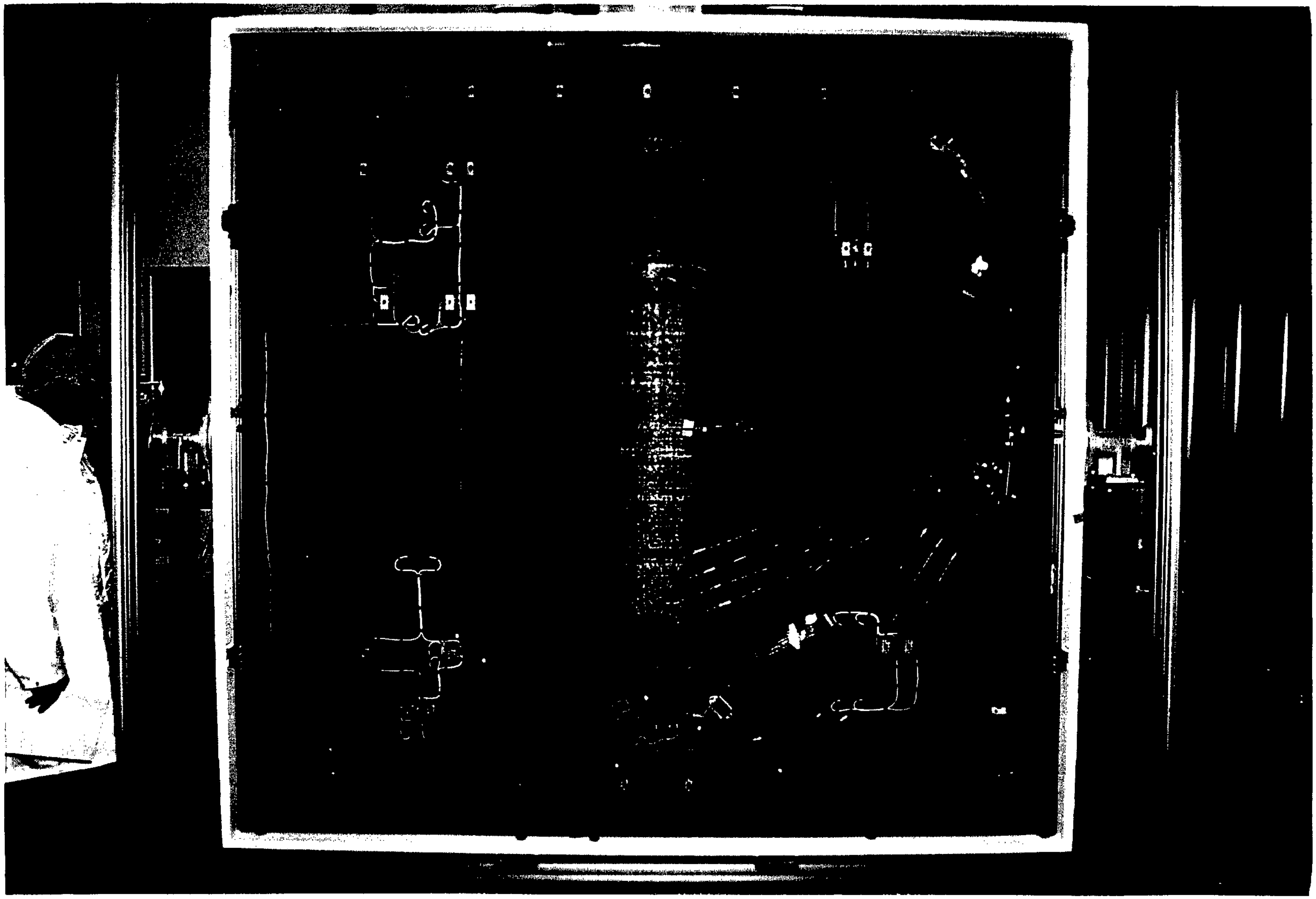

Figure 17. Proto-Flight Solar Array Panel - Wire Side

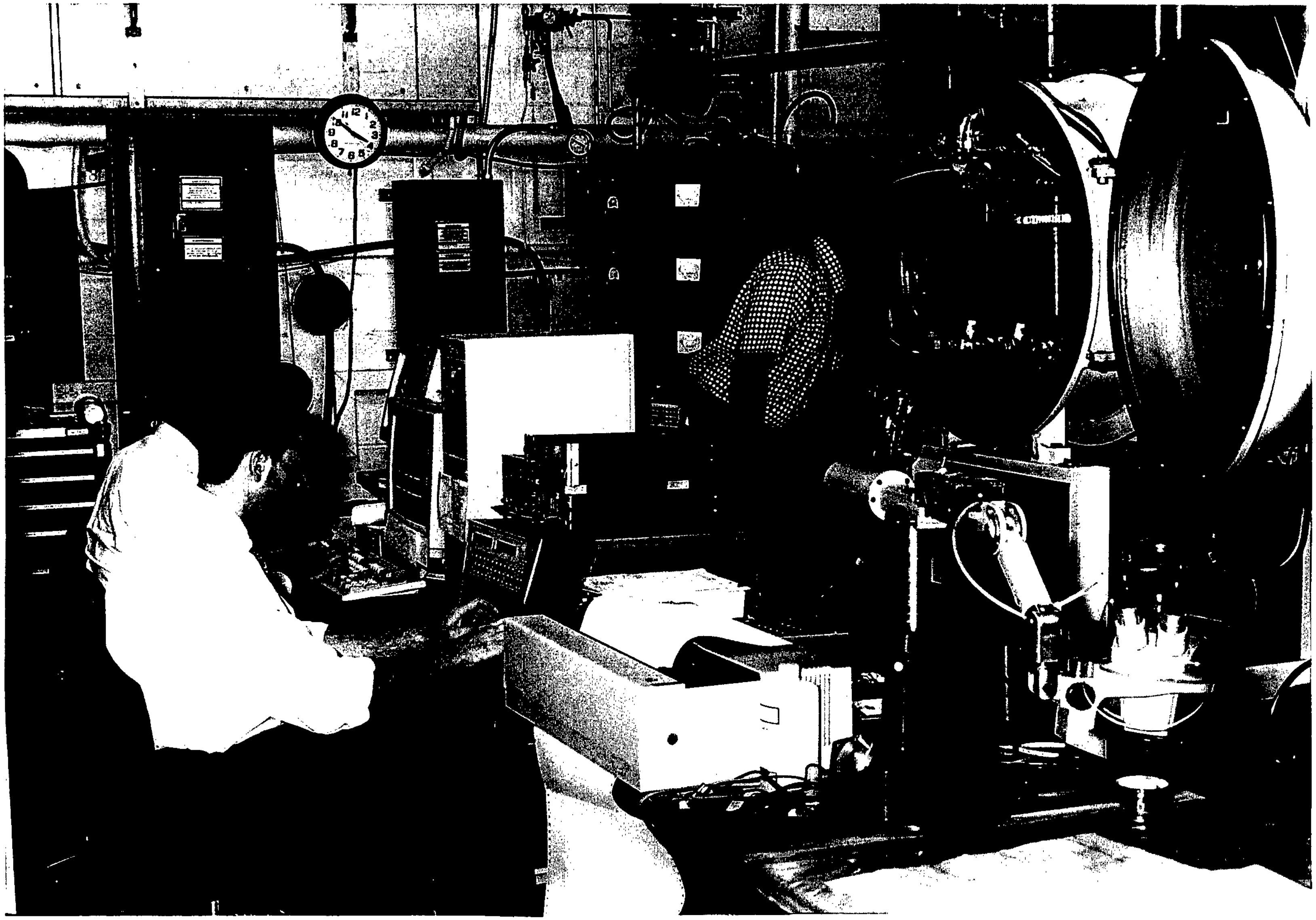

Figure 18. Microscope Inspection

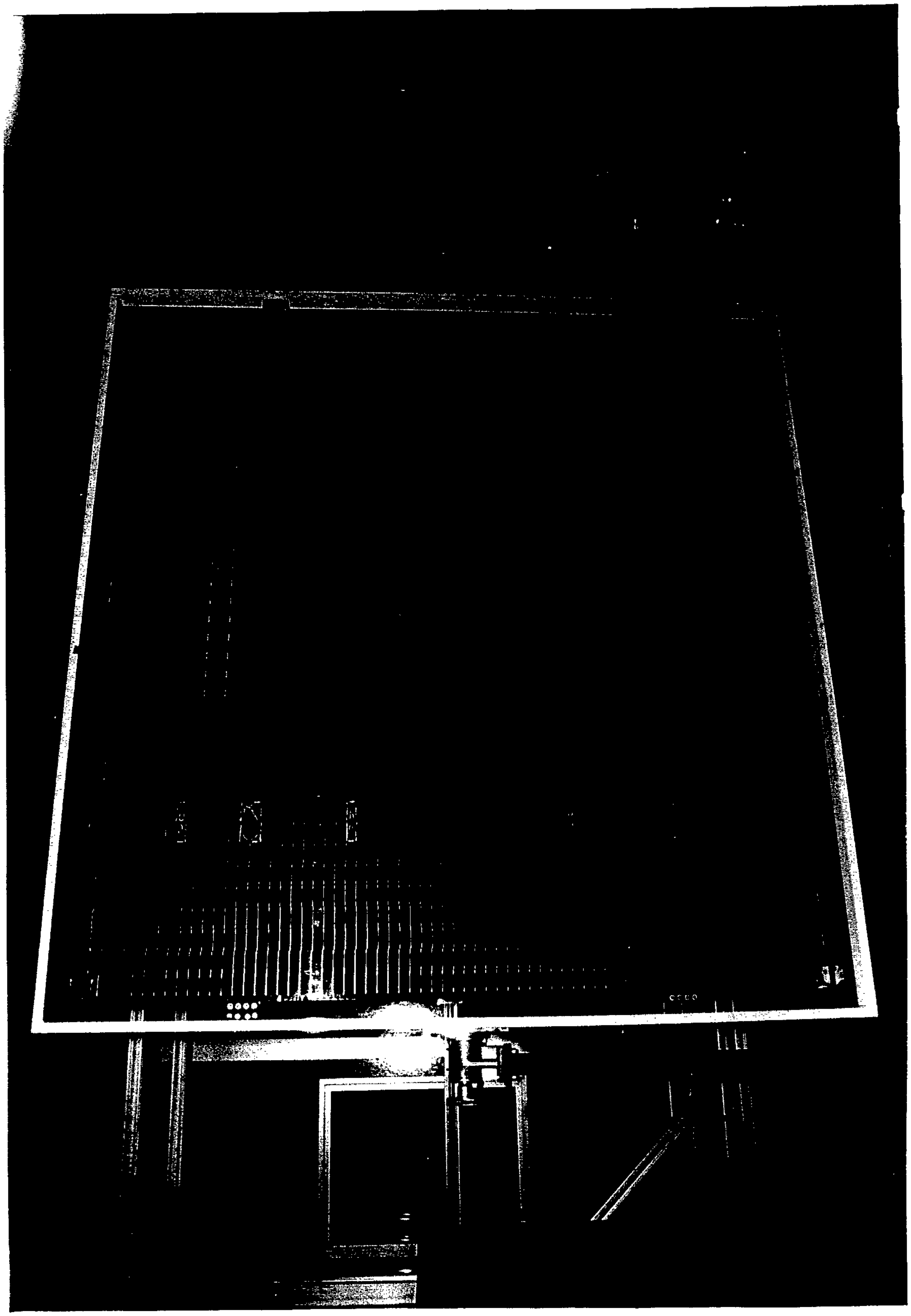

Figure 19. Proto-flight Handling Mechanism

Figure 20. Photo-flight IR Inspection System

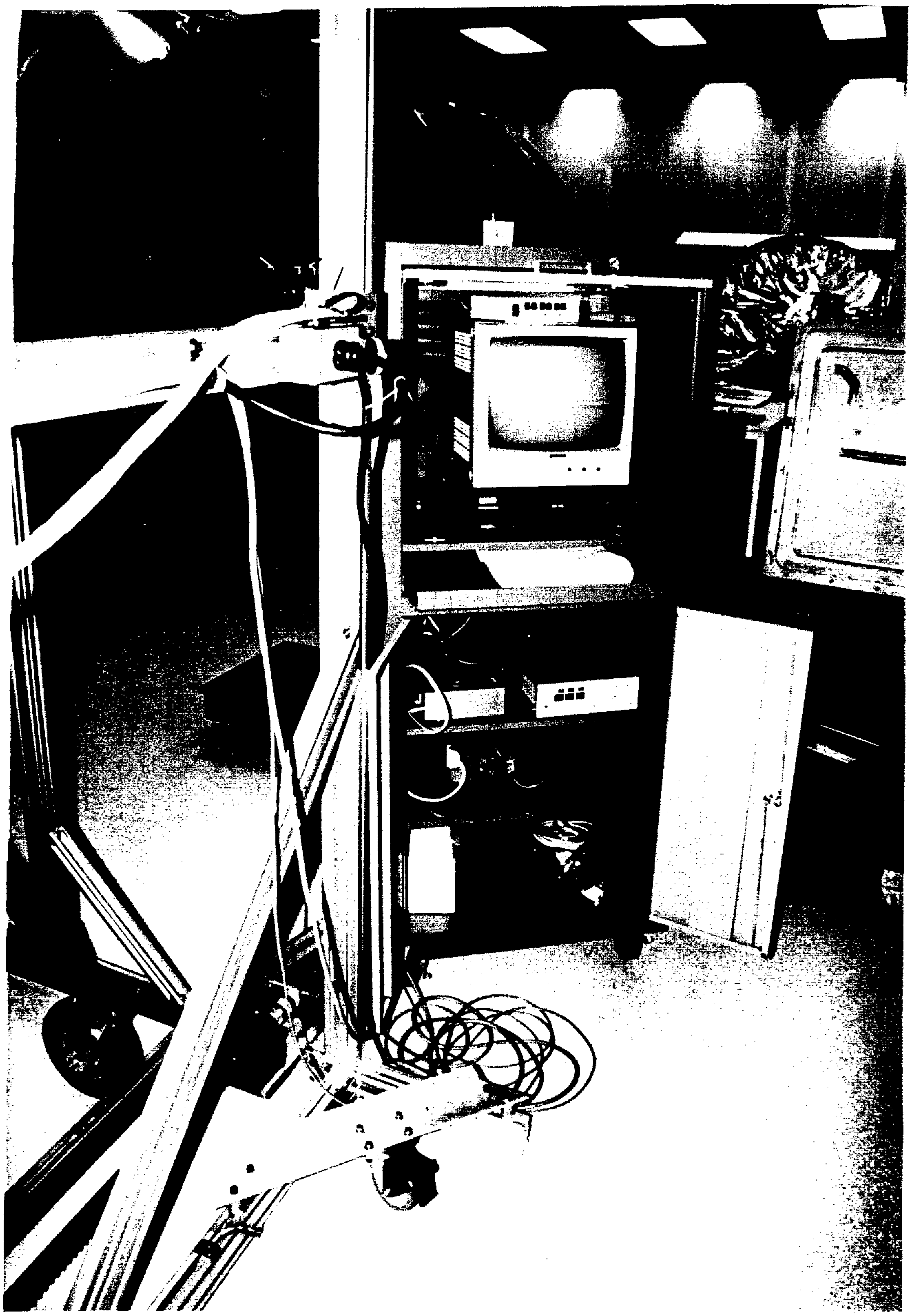

Figure 21. Proto-flight IR Control Unit

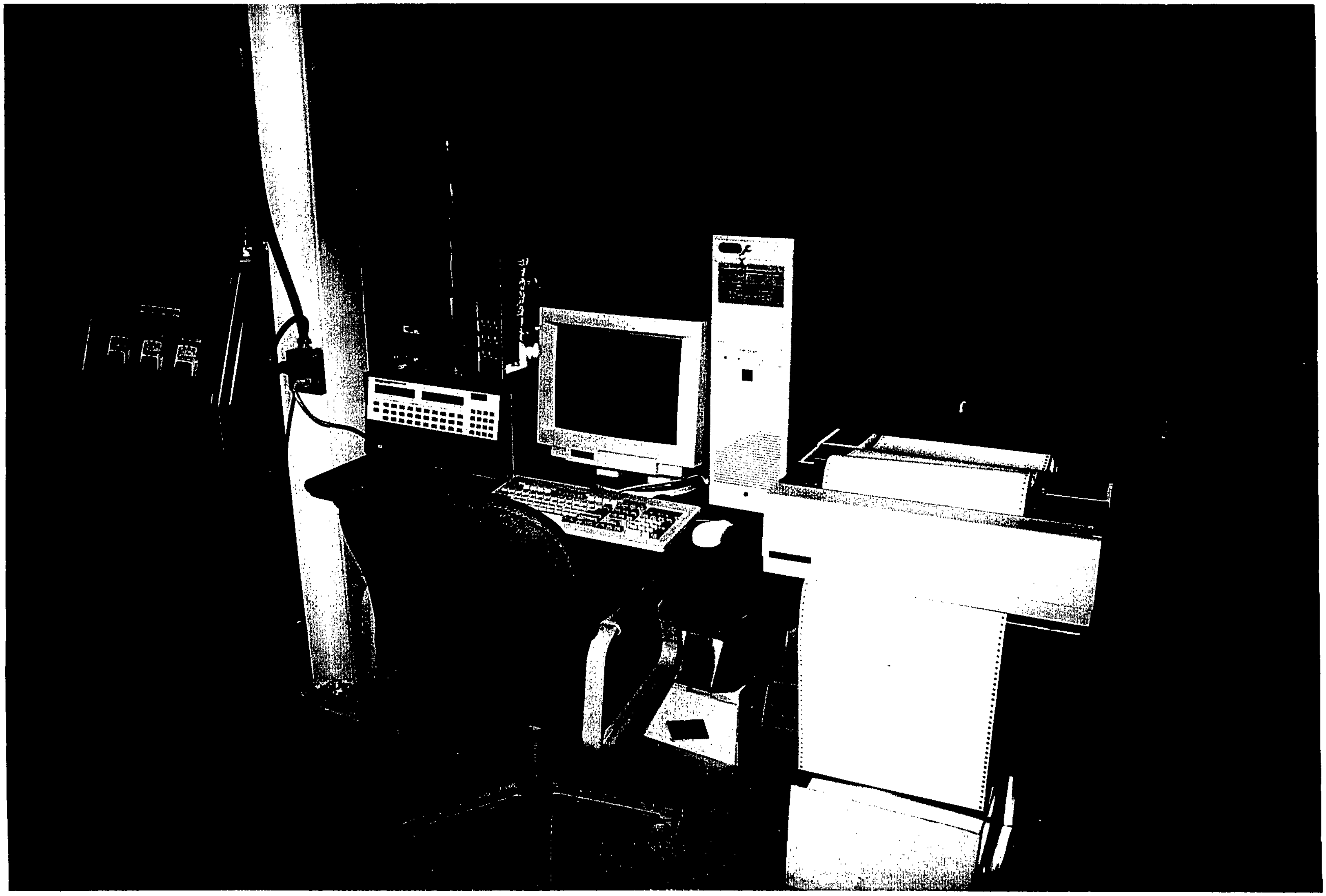

Figure 22. NASA-MSFC/TRW Proto-flight Test Equipment

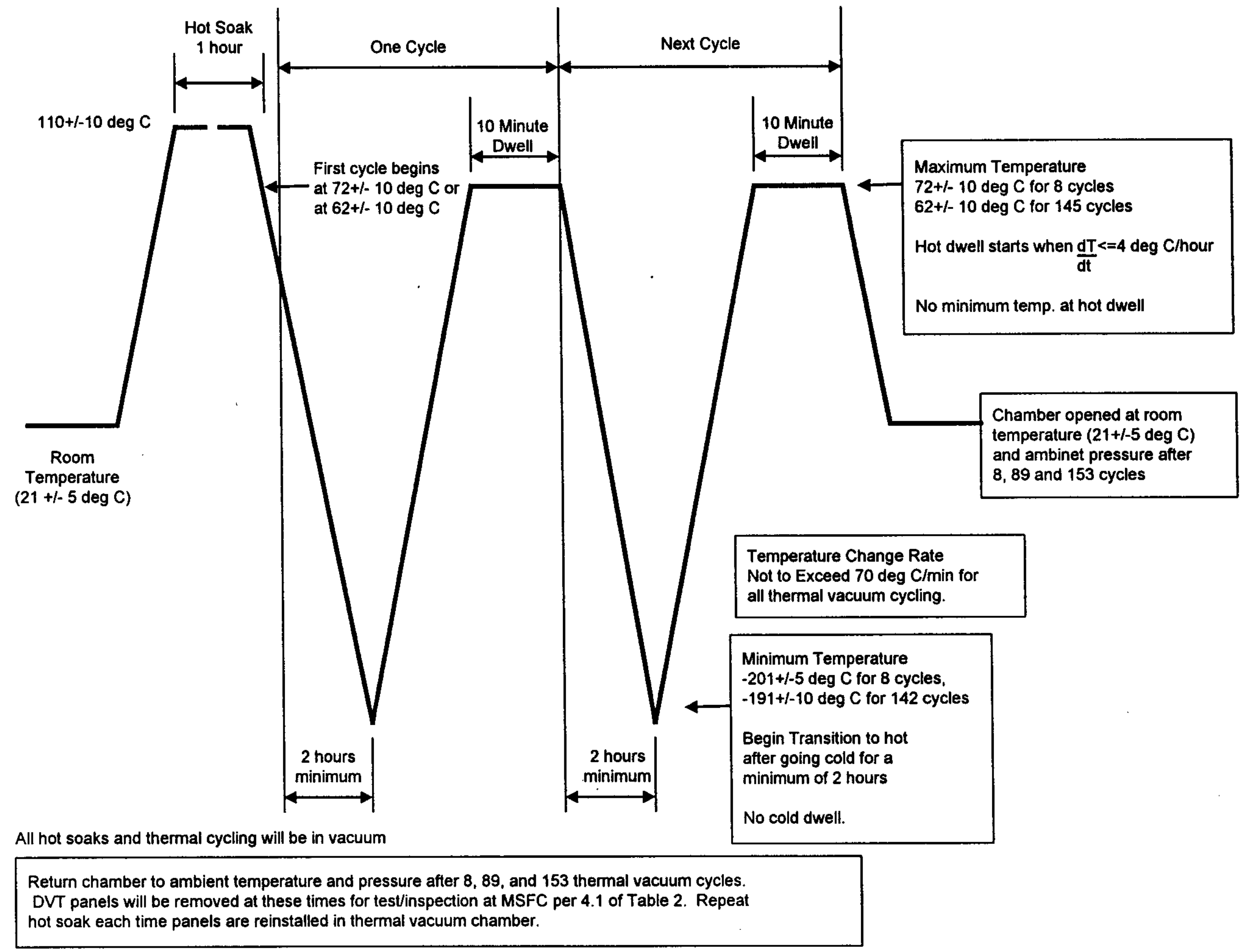

Figure 23. AXAF-I DVT Testing at AEDC: Hot Soaks and 153 T/V Cycles

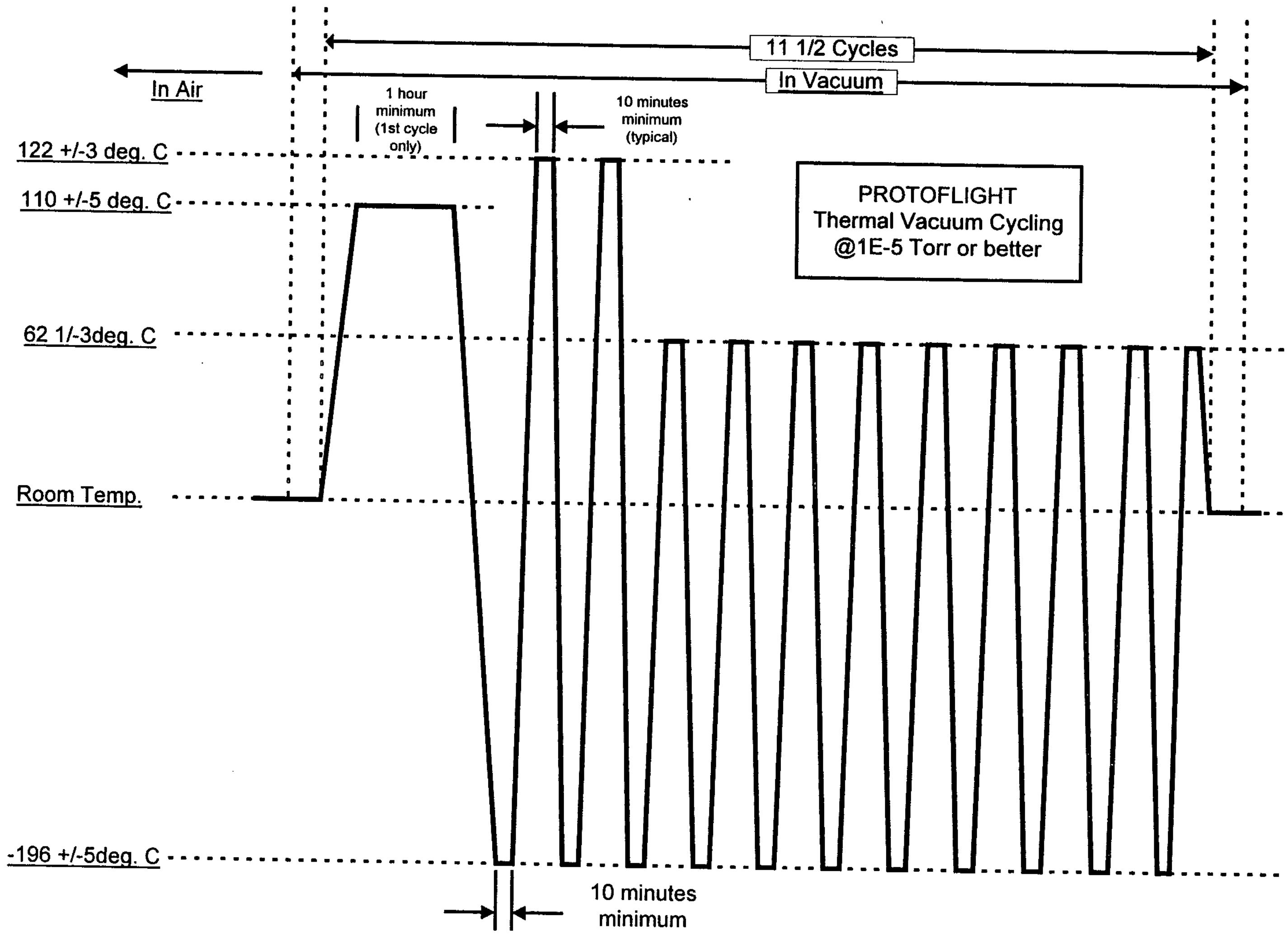

Figure 24. AXAF-I Proto-flight Testing at AEDC: Hot Soaks and 11-1/2 T/V Cycles

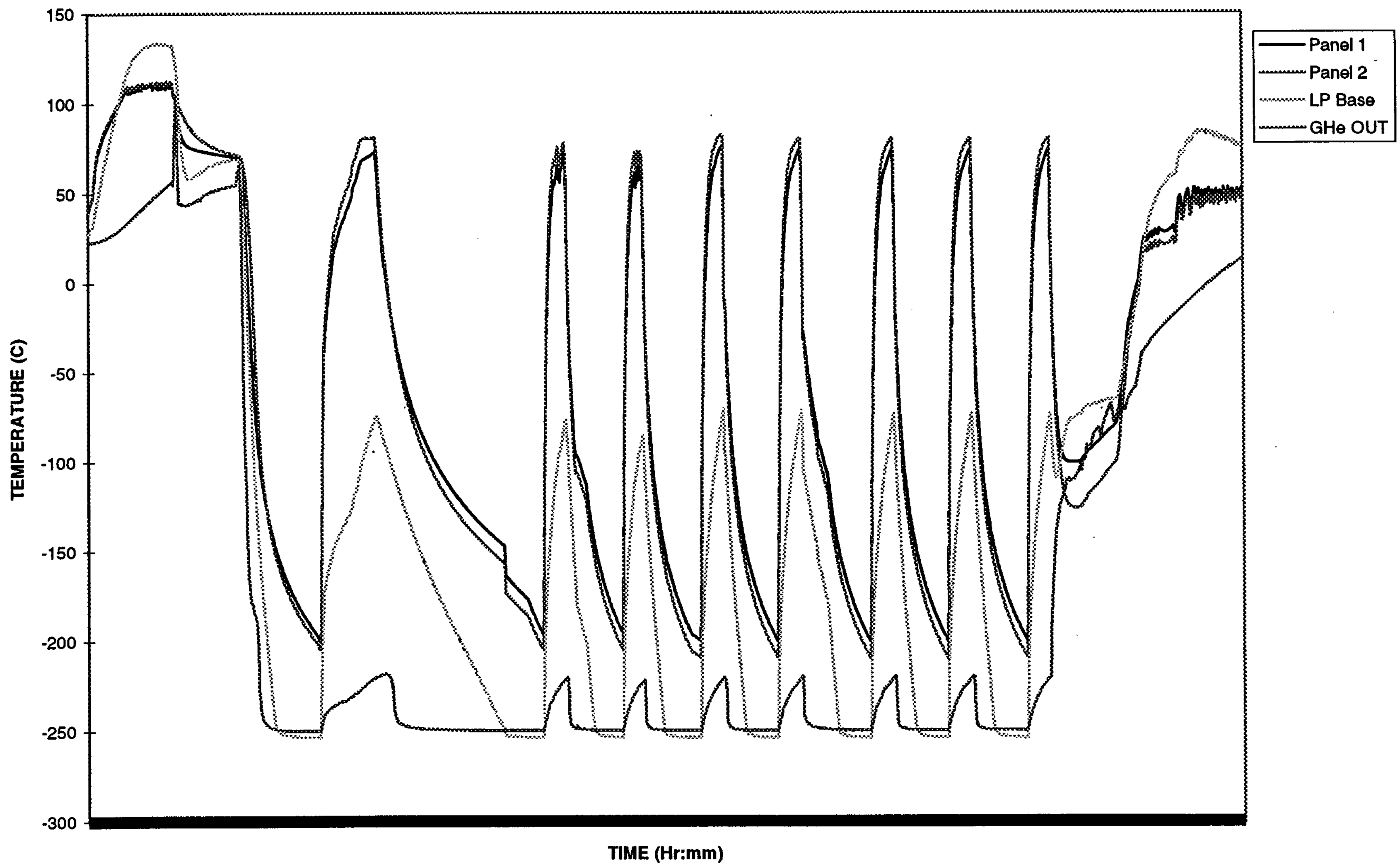

Figure 25. DVT Test Cycles 1-8

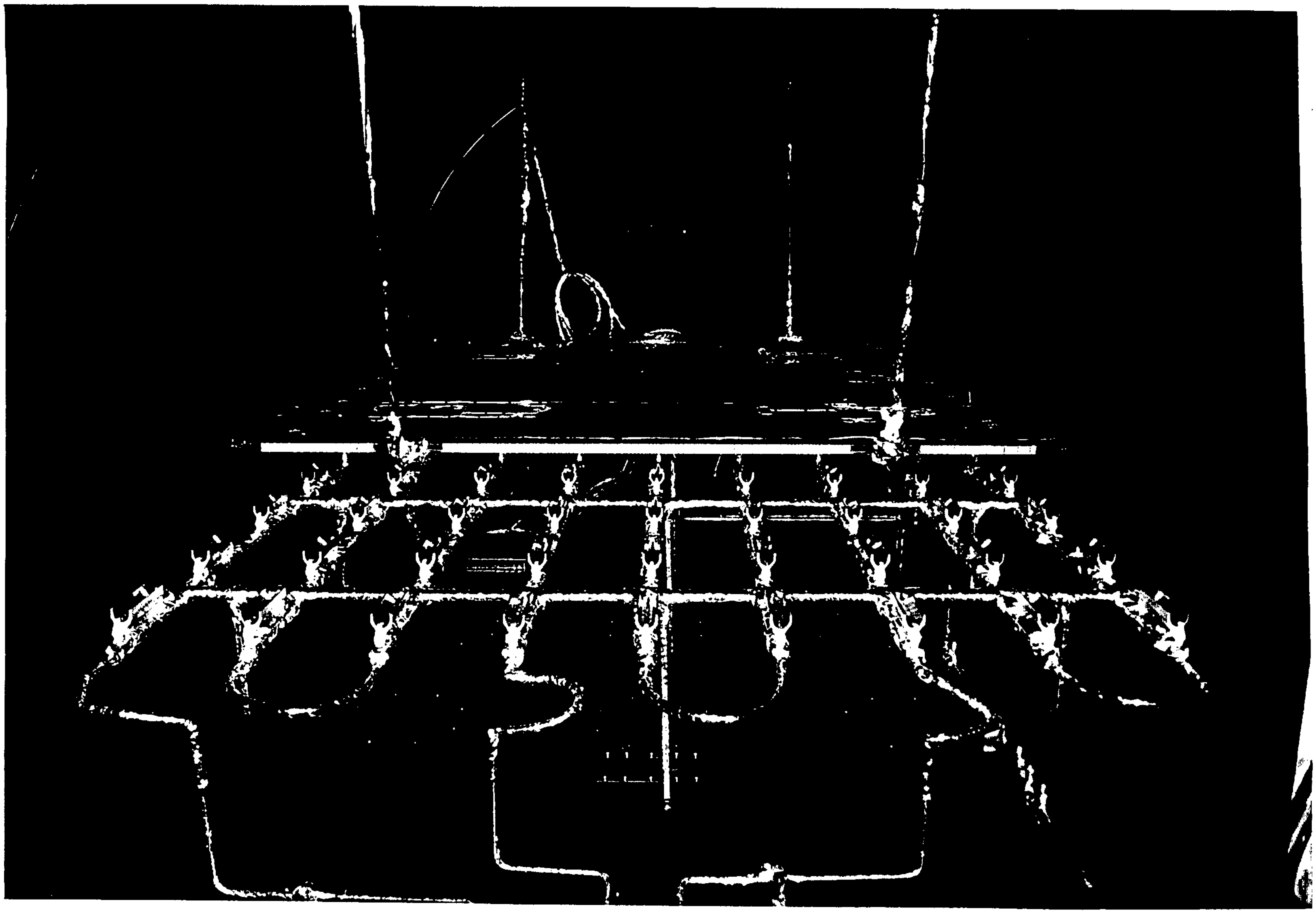

Figure 26. Proto-flight Solar Array Panel in 10V Chamber

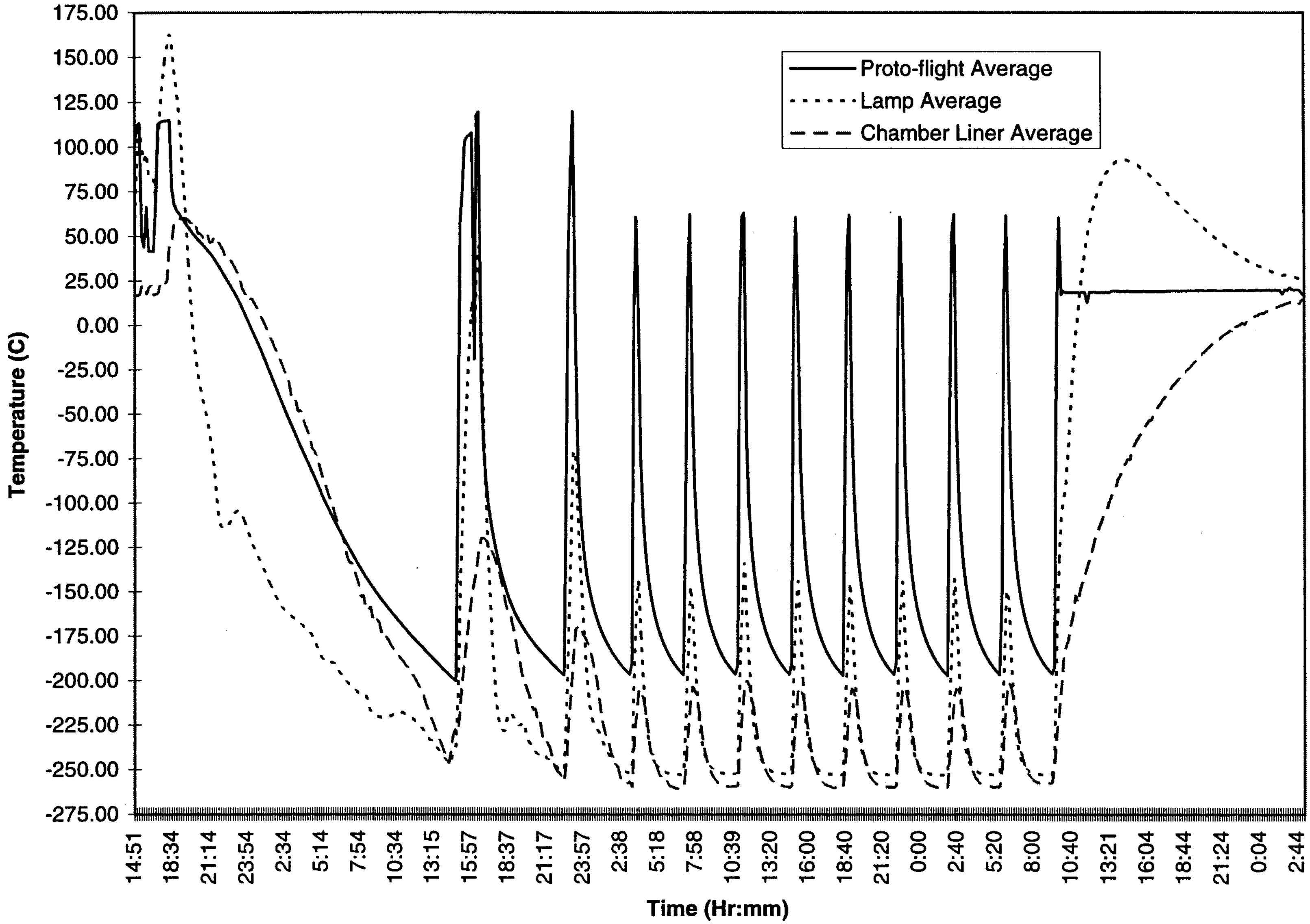

Figure 27. Proto-flight Solar Array Panel Thermal Cycles 1-11 1/2

Table 1. DVT Solar Array Panel Thermal Cycles 90-153 (1 - 64)

Day	Date	Completion Time	Cycle	Temperature
Sunday	2-Jul	17:57	1	-192
		21:55	2	-180
Monday	3-Jul	1:53	3	-180
		5:51	4	-180
		9:49	5	-180
		13:47	6	-180
		17:45	7	-180
		21:43	8	-180
Tuesday	4-Jul	1:11	9	-175
		4:41	10	-175
		8:11	11	-175
		11:41	12	-175
		15:07	13	-175
		19:50	14	-175
		23:16	15	-175
Wednesday	5-Jul	2:43	16	-175
		6:11	17	-175
		9:38	18	-175
		13:06	19	-175
		16:34	20	-175
		20:02	21	-175
		23:30	22	-175
Thursday	6-Jul	2:58	23	-175
		6:26	24	-175
		9:54	25	-175
		13:22	26	-175
		16:27	27	-170
		19:32	28	-170
		22:37	29	-170
Friday	7-Jul	1:42	30	-170
		4:47	31	-170
		7:52	32	-170
		10:57	33	-170
		14:02	34	-170
		17:07	35	-170
		20:12	36	-170
		23:17	37	-170
Saturday	8-Jul	2:22	38	-170
		5:27	39	-170
		8:33	40	-170
		11:03	41	-160
		13:33	42	-160
		16:03	43	-160
		18:33	44	-160
		21:03	45	-160
		23:33	46	-160
Sunday	9-Jul	2:04	47	-160
		4:35	48	-160
		7:06	49	-160
		9:37	50	-160
		12:08	51	-160
		14:39	52	-160
		17:10	53	-160
		19:41	54	-160
		22:12	55	-160
		0:43	56	-160
Monday	10-Jul	3:14	57	-160
		5:45	58	-160
		8:16	59	-160
		10:47	60	-160
		13:18	61	-160
		18:53	62	-192
		0:28	63	-192
Tuesday	11-Jul	6:03	64	-192
		12:00	Warmup	Open chamber.

Temp	Duration
-201	8 hr 2 min
-192	5 hr 35 min
-180	3 hr 58 min
-175	3 hr 30 min
-170	3 hr 4 min
-160	2 hr 28 min

Table 2. Proto-flight Solar Array Panel Thermal Cycle Times

Start Date	Cycle Number	Cycle Completion	Cycle Time	Hot Limit Temp (C)	Cold Limit Temp (C)	Notes
11/6/96	0	11/7/96 18:29	23:59	110	20	1
11/8/96	1	11/8/96 16:39	22:10	122	-196	2
11/8/96	2	11/8/96 23:23	6:44	122	-196	2
11/9/96	3	11/9/96 3:56	4:33	62	-196	2
11/9/96	4	11/9/96 7:42	3:46	62	-196	2
11/9/96	5	11/9/96 11:32	3:50	62	-196	2
11/9/96	6	11/9/96 15:18	3:46	62	-196	2
11/9/96	7	11/9/96 19:03	3:45	62	-196	2
11/9/96	8	11/9/96 22:48	3:44	62	-196	2
11/10/96	9	11/10/96 2:32	3:43	62	-196	2
11/10/96	10	11/10/96 6:15	3:43	62	-196	2
11/10/96	11	11/10/96 9:58	3:43	62	-196	2
11/10/96	12.0			20	20	3

Notes

1. Started Chamber Evacuation, Ambient Bakeout.
2. Tested with less than -260C background.
3. Warm Chamber to Ambient